THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

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	Page
General	
Resistance Sintering of Metal Powders	58
Chemical and Electrochemical Polishing of Metals and Alloys: Patent Literature	58
Nickel	
Specific Heat of Nickel	58
Polarization of Nickel and Nickel–Copper Alloys in Sodium–Chloride Solutions	59
Effects of Outgassing on Catalytic Activity of Nickel	59
Nickel Films Deposited by Thermal Processes or Chemical Precipitation	59
Nickel in Nuclear Engineering Equipment	59
Use of Nickel in Gas Purifier	60
Sintered–Powder Plates in Nickel–Cadmium Batteries	60
Photometric Determination of Nickel	61
Electrodeposition and Other Coating Methods	
Electroplating in 1954: Review	61
The Salt–Spray Test: Acetic–Acid Modification	61
Nickel–Chromium Plating of Magnesium–base Castings	61
Hardness and Wear–Resistance of Electrodeposited Metal Coatings	62
Non-Ferrous Alloys	
Symposium on Control of Quality in Production of Wrought Non–Ferrous Materials	62
Constitutional Studies on Alloy Systems: Bibliography	63
Nickel-Iron Alloys	
Transformations in Nickel–Iron Alloys	64
Phase Diagram for Carbon-containing Nickel–Iron Alloys	64
Segregation of Silicon in Nickel–Iron–base Alloys	64
Magnetic Materials: Properties and Uses	65
Magnetic Properties of Evaporated Nickel Films	65
Magnetostriction in Cobalt–Nickel–Iron Alloys	65
Fabrication of Nickel–Iron and Other High–Permeability Alloys: American Practice	66
Cast Iron	
S.G. Iron	
Thermal Stability	66
Impact Characteristics	66
Austenitic Cast Irons	66
High-Temperature Properties of S.G. Iron	67
S.G. Iron for Crankshafts	67
Constructional Steels	
Effect of Pouring Conditions on Structure of Steel Ingots	67
Influence of Vanadium on Transformations in Case–Hardening Nickel–Chromium Steel	67
Low–Alloy Nickel–Chromium–Molybdenum Steel	68
Spot Welding of Carbon and Low–Alloy Steels	68
Heat- and Corrosion-Resisting Materials	
Influence of Structure on Creep–Resistance of Austenitic Nickel–Chromium Steels	68
Relationships between Long– and Short–Time Properties in Nickel–Chromium–base Alloys	69
Iron–base High–Temperature Casting Alloy	70
Formation of Sigma in Molybdenum–containing Austenitic Steels	70
Dry Corrosion: Practical Problems	70
Aircraft Gas Turbines: Materials and Fabrication Methods	71
Resistance of High–Temperature Alloys to Scaling and Attack by Vanadium Pentoxide	72
Nickel–Chromium–Boron Brazing Alloy	74
Nickel–containing Alloys for Brazing of Molybdenum	75
Austenitic Nickel–Chromium Steel Welding Electrodes: Influence of Production Technique	76
Welding of Stainless Steels: Correlated Summary of Information	77
Overlaying of Steel and Cast Iron with High–Nickel Alloys	77
Influence of Cold Work and Tempering on Structural Changes in Austenitic Steel	77
Preserving the Corrosion–Resistance of Nickel–Chromium Stainless Steels	78
Anodic Protection of Stainless Steel in Nitric Acid, by Coupling with Aluminium	78
Corrosion by Alternate Exposure to Liquid and Gaseous Fluorine	78
Materials for Handling Hydrofluoric Acid	79
Spectrochemical Analysis of High–Nickel Alloys	79
Patents	79

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THE MOND NICKEL COMPANY LTD • SUNDERLAND HOUSE, CURZON STREET, LONDON W.1
Telephone:- Grosvenor 4131

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Resistance Sintering of Metal Powders

F. V. LENEL: 'Resistance Sintering under Pressure.' *Jnl. of Metals*, 1955, vol. 7, Jan., Sect. 2; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 158–67: T.P. 3883E.

The usual sequence of operations in commercial production by powder-metallurgy methods is to compact metal powders in a die at room temperature and subsequently sinter the compact, without applying pressure while the compact is in the sintering furnace. In hot-pressing, however, compacting and sintering operations are combined. Loose powder, or a preformed compact, is inserted into the die, which is held at the hot-pressing temperature, the compact is left in the die until it attains the required temperature, and pressure is then applied and maintained for a given length of time. The die may be heated by surrounding it with a suitable furnace, by high-frequency induction, or by passing current through the die.

One of the principal difficulties in hot-pressing is the lack of die materials which have adequate strength at the hot-pressing temperatures, and to overcome this problem a method has been developed by which only the material to be pressed is heated. This is effected by passing through the powder material a low-voltage, high-amperage current, with simultaneous application of pressure: the temperature required is produced by the power dissipated in the powder. This procedure, which is designated 'electrical-resistance sintering under pressure', is thus differentiated from conventional hot-pressing by the following characteristics:- (1) the sintering times required are very short, at most only a few seconds; (2) the powder and the die are initially cold; (3) heat is generated within the powder and is not conducted into it from the die; (4) the pressure used is high; (5) cooling is rapid, constituting a quench.

The present writer outlines the development of this idea (which originated as early as 1933), and gives a detailed account of research which has been carried out at the Rensselaer Polytechnic Institute, on behalf of the U.S. Navy. The work has covered an investigation of the basic characteristics of resistance sintering under pressure, vis-à-vis other powder-metallurgy techniques, and the applicability of the modified process to the production of nickel- and cobalt-base high-temperature alloys, refractory metals such as molybdenum, titanium, and some of their alloys, and cermets of various types.

The paper is limited to a description of the equipment used and a discussion of the basic characteristics of the resistance-sintering process, e.g., resistance requirements for powders and for compacts, temperature distribution in compacts, and gas reactions during resistance sintering. Applications of the process to individual materials, e.g., titanium, zirconium, Stellite alloys, 80–20 nickel-chromium alloys, and titanium-carbide-base cermets, are used only as examples to illustrate the discussion, but are not specifically related to the processing of the materials as such. The final section of the paper consists of a discussion of some potential applications of the new technique.

Hardness and Wear-Resistance of Electrodeposited Metal Coatings

See abstract on p. 62.

Chemical and Electrochemical Polishing of Metals and Alloys: Patent Literature

H. BAUR: 'The Chemical and Electrochemical Polishing of Metal Surfaces: Patents issued since 1940.' *Metalloberfläche*, *Sect. A*, 1955, vol. 9, Feb., pp. 22A–8A.

The review is in tabular form, covering patents of all countries, and classified according to the nature of the materials polished. The individual sections relate, respectively, to patents dealing with (*a*) *chemical polishing* of aluminium and its alloys; magnesium; iron and steel (including stainless steels); copper, nickel and their alloys; zinc and cadmium, and (*b*) *electrolytic polishing* of aluminium and its alloys; magnesium and magnesium-base alloys; iron and steel (including stainless steels); nickel, chromium and their alloys; copper and copper-base alloys; zinc, cadmium and their alloys; precious metals.

In each case the number of the patent is supplemented by information on date of issue, and composition of solution used, and in many instances temperature and other operating conditions are shown.

NICKEL

Specific Heat of Nickel as a Function of Temperature

F. KRAUS and H. WARNCKE: 'Specific Heat of Nickel between 180° and 1160°C.' *Zeitsch. f. Metallkunde*, 1955, vol. 46, Jan., pp. 61–9.

Temperature dependence of the specific heat of nickel was determined by two methods, full details

of which are given. The specimens used were of high-purity nickel, for which the following analysis is given: nickel 99·97, arsenic 0·0008, iron 0·0006, manganese 0·0001, silicon less than 0·0004, chromium less than 0·0003, copper less than 0·0003, per cent.

Polarization of Nickel and Nickel-Copper Alloys in Sodium-Chloride Solutions

H. B. BOMBERGER, F. H. BECK and M. G. FONTANA: 'Polarization Studies of Copper, Nickel, Titanium and Some Copper and Nickel Alloys in Three per cent. Sodium Chloride.' *Jnl. Electrochemical Soc.*, 1955, vol. 102, Feb., pp. 53–8.

Polarization characteristics were determined for copper, 70–30 brass, red brass, nickel, 70–30 copper-nickel alloy, Monel, and titanium, in flowing 3 per cent. sodium-chloride solutions. Relations between potential and time, potential and applied current, applied current and rate of corrosion, and solution velocity and rate of corrosion were considered. The results show that copper and brass anodes dissolved readily: nickel and copper-nickel alloys exhibited anodic polarization: titanium anodes resisted dissolution by film growth and extensive polarization. The data are correlated with those of other investigators who have studied the polarization properties of electrodes in relation to corrosion phenomena.

Effects of Outgassing on Catalytic Activity of Nickel

R. F. WOODCOCK and H. E. FARNSWORTH: 'Effects of Heat-Treatment and Ion-Bombardment Cleaning on the Catalytic Activity of a Pure Nickel Surface.' *Bull. Amer. Physical Soc.*, 1955, vol. 30, Jan. 27, p. 13. Abstract of paper presented to American Physical Society Annual Meeting, New York, January, 1955.

This paper reports investigations on the behaviour, in hydrogenation of ethylene, of nickel heat-treated in a high vacuum, cleaned by positive-ion bombardment, and subsequently annealed. Catalytic activity increased sharply with outgassing in vacuum at temperatures up to 800°–900°C. Immediately after bombardment the catalytic activity was found to be greater than that resulting from heat-treatment alone, but on annealing at 600°C. for approximately one minute, after bombardment, activity was reduced to zero. Possible interpretations of these results are discussed.

Nickel Films Deposited by Thermal Processes or Chemical Precipitation

S. WEIN: 'Nickel Films.' *U.S. Dept. of Commerce, Office of Technical Services, Report P.B.* 111330; 14 pp. Price 1 dollar.

This report, prepared in co-operation with a U.S. Navy Bureau of Aeronautics Contract, comprises an annotated survey of the technical and some patent literature on nickel films deposited by thermal decomposition of nickel compounds, and by chemical precipitation from various types of solution. In some of the sections, e.g., that covering deposition via the carbonyl, deposition of other metals is also considered.

Nickel in Nuclear Engineering Equipment

'Nuclear Engineering, Part I.' *Published by Amer. Inst. Chemical Engineers, in Chemical Engineering Progress Symposium Series*, 1954, vol. 50, No. 11; vii+280 pp.

This volume contains preprints of some of the papers presented at a meeting on nuclear engineering, sponsored by the American Institute of Chemical Engineers and the University of Michigan, in June 1954. The meeting was the first international congress on the peacetime uses of atomic energy. The papers in this set of records cover reactor technology, materials of production, engineering research and education in this field, reactor statistics, and reactor products. They include contributions from authors in many countries.

Attention is directed below to two papers which are of interest in relation to the use of nickel:—

J. G. BEACH and C. L. FAUST: 'Electrocladding of Reactor Materials', pp. 31–8.

The authors discuss the advantages (corrosion- and galling-resistance, etc.) which may be gained by the use of electrodeposited metal coatings, and also draw attention to certain limitations imposed by the nature of the operations involved in nuclear plant (need for neutron economy, diffusion of coating and base metals liable to occur at service temperatures, etc.).

Reviewing the metals which are being used for such services, the following statements are made:—'Aluminium is being electrodeposited in thicknesses up to 30 mils. It has acceptable resistance to corrosion, has a low thermal-neutron-absorption cross section, and is stable under radiation. Nickel is also a good all-round metal for coating: it has desirable chemical and physical properties and at controlled thicknesses has several applications. Iron coatings are also useful in some cases, but because of its poorer resistance to oxidation iron is less generally useful than nickel. Electrodeposited coatings of beryllium, magnesium, zirconium, molybdenum and titanium may also find some applications in nuclear plant, but to date these metals have been electrodeposited from fused salts only and it will be necessary to develop other methods of deposition in order to make them useful for such purposes.'

The authors emphasize the importance of correct preparation of basis metals for electroplating: they discuss the following aspects of the subject:—machining and surface finishing, activation of surfaces of aluminium, beryllium, magnesium and zirconium for electroplating with nickel or other metals, and the technique for deposition of nickel, iron, chromium, bismuth, and aluminium on the respective bases. Typical photomicrographs show nickel coatings on beryllium, illustrating the nickel surface, the alloyed layer between the two metals, and the beryllium base.

With regard to the use of coated metals in nuclear equipment operating at high temperatures, it is pointed out that, in general, alloying under service conditions is undesirable, since a constantly changing system will thus be set up. If such diffusion occurs, the rate of alloying will vitally affect the useful life of an electroplated part. Controlled diffusion brought about by heat-treatment after electrodeposition can, however, contribute to good bonding of the coating to the basis metal: for example, diffusion alloy bonds can be obtained between zirconium and a nickel coating by heating for various times at temperatures in the range 1200°–1500°F. (650°–815°C.). Appreciable alloying between a beryllium base and the nickel coating, on the other hand, destroys the bond: this effect is illustrated.

E. M. SIMONS and J. H. STANG: 'Engineering Problems Pertinent to the Use of Sodium Hydroxide in Reactors', pp. 139–44.

Anhydrous molten sodium hydroxide shows considerable promise as a reactor liquid, but many problems are being encountered in its use in closed circulating systems operating at high temperatures. The most urgent of these is that of finding a container material which will give reasonable life at temperatures above 1000°F. (540°C.). Of the very large number of materials which have been subjected to static-corrosion tests, none has proved to be completely immune from attack. The most promising is nickel, but its usefulness in non-isothermal systems is seriously affected by the tendency for metal transfer (see, for example, experience reported in *Corrosion*, 1954, vol. 10, Dec., pp. 435–9; *Nickel Bulletin*, 1955, vol. 28, Feb., p. 27). In the present paper an example is shown of corrosion occurring in a test rig in which needle-like crystals of nickel were transferred from the container (hot zone) and deposited in the cooler zone of the equipment.

Extensive study of this phenomenon has indicated that it is not due to simple differential solubility of nickel in sodium hydroxide. Attempts to hinder mass transfer by the addition of additives to the caustic or by the use of high-purity materials have not been successful, and the only means of lessening the corrosion at present devised is the use of a reducing, in place of a neutral or oxidizing, atmosphere.

This modification has reduced the amount of material removed from the hot to the cooler zone, but the degree of corrosion is still too great to permit long-time use of sodium hydroxide in large-scale heat-transfer systems operating at peak temperatures of 1200°–1500°F. (650°–815°C.). Laboratory tests indicate that at lower temperatures (e.g., up to 1000°F.: 540°C.) the amount of metal transfer is reduced to a degree which would indicate the possibility of operation of such systems for as long as six months before flow and heat-transfer were seriously impaired by metal-crystal build-up.

The authors also discuss problems associated with other components of reactors, e.g., pumps, seals, bearings, valves, piping, etc., and measuring devices employed in such plant.

Use of Nickel in Gas Purifier

L. LANDECKER and A. J. GRAY: 'Diffusion of Gases through Nickel and Design of a Convenient Leak for Hydrogen and Deuterium.'
Rev. Scientific Instruments, 1954, vol. 25, Dec., pp. 1151–3.

For many years thin-walled tubes of palladium have been used for purification of hydrogen, but since this metal has some inherent limitations, an investigation of the behaviour of nickel as an alternative was made.

Diffusion of hydrogen and of deuterium through thin-walled nickel tubing was studied over the range 200°–1000°C. At the temperature at which the most detailed experiments were made (500°C.), with a pressure difference of 1 atmosphere, it was observed that these two gases diffuse through such tubing about 2000 times as fast as nitrogen or air. The authors describe design and operation of a hydrogen and deuterium leak in which a nickel tube is embodied.

Sintered-Powder Plates in Nickel-Cadmium Batteries

L. G. HECTOR: 'What the Nickel-Cadmium Battery can do for Fleet Operators.' *Soc. Automotive Engineers, Preprint* No. 395, Oct., 1954; 3 pp. + figures.

The subject of the paper is the Sonotone sintered-plate nickel-cadmium alkaline battery, which, having reached production stage immediately prior to the Korean war, was extensively developed for military use during the years 1949–1953, and is now being supplied in the U.S.A. for civilian use in automobiles, buses, Diesel locomotives, mining equipment, aircraft, and marine applications.

Among the advantages claimed for this type of battery are its very long service life: accelerated life tests consisting of 3,000 cycles of complete discharge and re-charge (equivalent to ten years' of hard use) caused no loss in battery capacity. Complete discharge results in no deterioration: the battery will return to full capacity on being correctly charged. It is mechanically rugged, and has proved easily able to withstand specially severe shock and vibration tests, as well as those normally applied under military specification. The ability of the sintered-plate battery to operate at low temperature (it will start an engine at −65°F.: −54°C.) is a further noteworthy feature, and it also operates satisfactorily at temperatures up to +165°F. (+74°C.). Due to the combined mechanical and chemical characteristics of the sintered-plate battery, it is able to deliver high currents in proportion to its size and ampere hour rating, and this fact, combined with its ability to accept charge rapidly, makes possible the use of smaller, lighter batteries on trucks, so giving an advantage in pay load.

Chemical and Electrochemical Polishing of Metals and Alloys: Patent Literature

See abstract on p. 58.

Photometric Determination of Nickel

'Photometric Methods of Analysis. A Survey of Recent Methods.' *Chemical Age*, 1955, vol. 72, Feb. 26, pp. 527–34, 542.

This survey of literature, supported by a *bibliography* of 212 references, briefly summarizes recent work on the use of photometric methods for the determination of over 50 metals, of cyanide, and of nitrogen. Applications in organic analyses are also reviewed.

With regard to determination of nickel the following notes are given:—

'Russian authors [1] have reported on the use of α-furyldioxime for the gravimetric and colorimetric determination of nickel. The compound extracts well into benzene or chloroform at pH 7·3–8·4. GILLIS and co-workers [2] have used heptoxime (cycloheptanedionedioxime) for the colorimetric determination of nickel in the range 1–10 μg. The yellow complex, precipitated from acid solution, is much more soluble in chloroform than the nickel-dimethylglyoxime compound, and the extraction is quantitative over a wide pH range (3·8–11·7). Cobalt (II), copper (II), and iron (II) are the only metals to yield extractable heptoximates, but these can be controlled by addition of thiosulphate. The use of 2-nitroso-1-naphthol-4-sulphonic acid for the spectrophotometric determination of nickel has been proposed [3].'

(1) Jnl. Anal. Chem. U.S.S.R., 1953, vol. 8, p. 114.
(2) Chim. Anal., 1954, vol. 36, p. 43.
(3) Jnl. Anal. Chem. U.S.S.R., 1954, vol. 9, p. 134.

ELECTRODEPOSITION AND OTHER COATING METHODS

Electroplating in 1954: Review

N. HALL: 'Technical Developments of 1954.' *Metal Finishing*, 1955, vol. 53, Jan., pp. 58–66.

This survey (supported by a *bibliography* of 285 items) reviews recent developments, in the following classification:—

Cleaning, Pickling, Polishing.
Plating and Anodizing of Aluminium and Aluminium Alloys.
Metallic Coatings—
  Nickel, Chromium, Copper, Other Metals, Alloys.
Metallizing: Vacuum and Vapour Processes.
Conversion Films: Corrosion Preventives.
Testing and Control.
Miscellaneous.

The section relating to nickel coatings includes reference to 127 items of technical and patent literature.

The Salt-Spray Test: Acetic-Acid Modification

W. D. MCMASTER: 'The Five per cent. Salt-Spray Test and its Acetic-Acid Modification.' *A.S.T.M. Bull.*, 1955, No. 203, Jan., pp. 62–9; T.P. 23.

Report sponsored by A.S.T.M. Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.

The history of the salt-spray test is traced, with notes on the principal reports which have contained expressions of opinion on the validity of the test. Particular reference is made to the conclusions which have been drawn with regard to problems involved in the use of a 20 per cent. sodium-chloride solution, and to the employment of a 5 per cent. solution as an alternative. Attention is then directed to the findings of the A.S.T.M. Committee, that neither the 20 nor the 5 per cent. straight sodium-chloride solution is satisfactory for evaluation of copper-nickel-chromium coatings on steel or on zinc-base die castings, or for cadmium plating on steel. This conclusion resulted in consideration of a solution modified by addition of acetic acid. Following the development, in 1945, of a 20 per cent. sodium chloride solution containing 1 per cent. glacial acetic acid, tests showed that the addition of acetic acid to the 5 per cent. solution was also beneficial, and tests have confirmed the suitability of this modified spray for adoption as standard for accelerated evaluation of plated parts of many types, anodized and phosphatized aluminium and aluminium alloys, and other items. The report and recommendations made are based on ten years' investigation by the sponsoring Committee. The proposals are supported by a considerable amount of experimental data.

Nickel-Chromium Plating of Magnesium-base Castings

'Magnesium Castings: Chromium Plated.' *Light Metals*, 1955, vol. 18, Feb., pp. 56–7.
Based on paper by L. D. GODDEYNE and D. J. GODDEYNE, presented before The Magnesium Association, November, 1954.

The paper dealt with the first application of the Dow process for electroplating of magnesium-base materials in mass production: the development was specifically related to plating of die-cast cases for rules and other instruments.

The main features of the plating cycle adopted are outlined below:—

Initial pickling is in an aqueous solution of the following composition:—

Chromic acid (CrO_3)	.. .. ..	37½ oz.
Conc. Nitric acid (70% HNO_3)	..	3¾ oz.
Hydrofluoric acid (60% HF)	.. ..	1 fl. oz.
Water	to make	1 U.S. gal.
Temperature	.. ..	70–90°F. (21°–32°C.)

The castings are pickled for 1–3 minutes, according to the age of the bath, in a rotating tank lined with Koroseal. The tank is surrounded with a refrigerated water jacket, to prevent excessive temperature rise of the bath when a large quantity of castings is being treated. After pickling, the castings are rinsed in water and dipped in a weak alkaline solution, to counteract residual chromic acid.

After machining and cleaning, and prior to zinc-

immersion coating, the surface is activated by immersion for 20 seconds in an aqueous solution containing:—

Phosphoric acid (85% H_3PO_4) ..	1·6 pints
Sodium, potassium, or ammonium acid fluoride ($NaHF_2$, HKF_2 or NH_4HF_2)	13⅓ oz.

The bath is used at 70°–90°F. (21°–32°C.)

After some experiment, a zinc-immersion bath of relatively low concentration has been selected as giving the best all-round results: its composition is given as:—

	Oz.
Tetrasodium pyrophosphate ($Na_4P_2O_7$) ..	16
Zinc sulphate monohydrate ($ZnSO_4.H_2O$) ..	4
Potassium fluoride (KF)	0·94
Potassium carbonate (K_2CO_3)	0·67
Water	to make 1 U.S. gal.

The bath (pH 10·0–10·6 colorimetric) is operated at 175°–180°F. (80°–82°C.), with mild agitation.

After application of the zinc-immersion coating, the parts are flashed with copper from a Rochelle copper-strike solution, and are then copper-plated from a pyrophosphate bath modified by the addition of potassium fluoride (30–60 g. per litre). This type of solution was selected as having a wide brightness range and as not presenting so serious a waste-disposal problem as a cyanide bath. A minimum of 0·0008 in. of copper is deposited from this bath, operated at 130°F. (54°C.) for about 35 minutes at 25 amp. per sq. ft.

For nickel plating a Watts-type nickel solution with added brightener is used; pH 4·5. Parts are coated with a minimum of 0·0002 in. of nickel, obtained in about 15 minutes at 25 amp. per sq. ft., at 130°F. (54°C.). Provided that the underlay coatings are satisfactory, little difficulty is experienced in final chromium plating, using a standard chromic acid bath.

Hardness and Wear-Resistance of Electrodeposited Metal Coatings

R. WEINER and G. KLEIN: 'Hardness and Wear-Resistance of Electrodeposited Metal Coatings.' *Metalloberfläche*, Sect. B, 1955, vol. 7, Jan., pp. B1-B7.

The authors report micro-indentation hardness, scratch hardness, and frictional-wear tests, on a wide range of electrodeposited coatings. No close and consistent relation could be established among the three sets of measurements, and it is shown that, in particular, it is unsafe to assume a parallel between indentation hardness and resistance to wear. Scratch hardness gives a closer approximation, and it was found that a sharp fall in scratch hardness, in comparison with indentation hardness, is indicative of deterioration in wear-resisting quality.

Comparison of the properties of deposits made from 'special' bright-plating baths showed that these are not always harder than those made from normal types of electrolyte, and even when the indentation hardness of the bright deposits is higher than that of the normal coatings such difference may be associated with a lower degree of wear-resistance.

The tests were made on coatings of various types of brass, copper, chromium, nickel, silver, zinc, and cadmium.

Nickel Coatings in Nuclear Engineering Equipment

See abstract on p. 59.

NON-FERROUS ALLOYS

Symposium on Control of Quality in Production of Wrought Non-Ferrous Materials

'Symposium on the Control of Quality in the Production of Wrought Non-Ferrous Metals and Alloys. III. The Control of Quality in Heat-Treatment and Final Operations.' *Jnl. Inst. Metals*, 1954–55, vol. 83, Feb., pp. 193–270.

The scope of the individual papers contributed to this symposium* is indicated below:—

W. G. SHILLING: 'Assessment of Quality of Wrought Products', pp. 193–8: Advance Copy 1589.

An outline is given of the system of inspection used by the Aeronautical Inspection Directorate (Ministry of Supply). Specification requirements, test methods, the use of statistics, and heat-treatment and finishing processes are considered.

A. J. FIELD: 'The Control of Quality in Heat-Treatment and Final Operations in the Production of Rolled, Extruded, and Drawn Aluminium and Aluminium Alloys', pp. 199–220; Advance Copy 1590.

Qualities requiring control during heat-treatment and final operations are dimensions, shape, mechanical and physical properties, and surface and edge quality. The importance of earlier operations, as contributory to achievement of satisfactory results, is emphasized, and reference is directed to literature dealing with initial stages of production. The present paper describes, for each main product group in the aluminium and aluminium-alloy series, the various processes employed and the precautions required. The classification used is as follows:- Flat sheet, plate and circles, non-heat-treated; coiled strip non-heat-treated; heat-treated sheet and plate; heat-treated coiled strip; extruded and drawn shapes.

H. J. MILLER: 'Heat-Treatment and Finishing Operations in the Production of Copper and Aluminium Rod and Wire', pp. 221–32; Advance Copy 1591.

In view of the importance of surface quality of wire products, a broad review is made of the factors affecting it. General consideration is then given to characteristics of copper which are of primary importance in annealing, and commercial annealing

* Earlier symposia in this series dealing, respectively, with Control of Quality in (I) Melting and Casting, and (II) Working Operations, have been issued in the *Institute of Metals Monograph and Reports Series*, Nos. 15 and 16.

processes are discussed, with particular reference to their influence on control of quality. The testing of copper wire is also described, with special emphasis on assessment of springiness. The author also deals with annealing and other heat-treatment of aluminium and aluminium-alloy wires.

V. B. HYSEL and T. W. COLLIER: 'The Control of Quality in the Heat-Treatment and Finishing of Copper and Copper-base Alloys', pp. 233-46; Advance Copy 1952.

Heat-treatment applicable to various groups of material falling within this classification is discussed under the following headings: controlled-atmosphere annealing; heat-treatment of copper-base alloys of the precipitation-hardening type (chromium-copper, beryllium-copper, and copper-nickel-silicon alloys); heat-treatment of complex aluminium bronzes; removal of internal stresses. The second section covers a review of final shaping processes:—shearing of sheet; slitting of strip; manufacture of circles; straightening, cutting to length and deburring of bars and sections, and of tubes. Inspection procedures discussed include methods used for control of composition, surface quality and internal defects, and dimensions; mechanical and electrical tests; the mercurous nitrate test for detection of residual stresses; grain-size determination, and special tests. In this paper, as in others in the symposium, procedure adopted in packaging and dispatch is described, in so far as it affects control of final quality of the product.

W. T. EDMUNDS and R. C. LLOYD: 'The Production of Light-Alloy Drop Forgings, their Heat-Treatment, Inspection and Testing', pp. 247-61; Advance Copy 1593.

The importance of close liaison between the designer and manufacturer of drop forgings is emphasized. A detailed comparison is made among the different types of aluminium-alloy forging stock, with reference to forgeability and the quality of the product. Heat-treatment, methods of inspection, and types of defect commonly found are discussed, together with consideration of the inter-relationship of macrostructure, microstructure, and mechanical properties. Examples are also given of current practice in drop forging of magnesium alloys.

W. BETTERIDGE and T. E. COUND: 'The Heat-Treatment, Inspection and Testing of Wrought Nickel and Nickel Alloys', pp. 262-70; Advance Copy 1594.

Nickel and nickel alloys are distinguished by a number of 'special' properties, for which inspection and test procedures of somewhat unusual types are required. Typical examples are described in this paper. The alloys considered fall into three main groups:—

(1) Nickel and its alloys with iron, cobalt, copper, manganese and silicon, which are relatively soft, and can be easily hot- and cold-worked.

(2) Nickel-chromium and nickel-chromium-iron alloys, of the types characterized by high electrical resistance and good resistance to scaling at high temperatures. Such materials are much more difficult to work, either hot or cold, than those referred to in group (1).

(3) Creep-resisting alloys, based on the nickel-chromium or nickel-chromium-cobalt systems, which are difficult to hot-work, and can be cold-worked only by the aid of frequent inter-stage annealing.

Brief reference is made to methods used in production of bar, forgings, sheet and strip, wire, and tube, in alloys falling into one or more of the above groups, and a detailed account is given of specialized heat-treatment, testing, and inspection methods applied after the forming processes.

In connexion with heat-treatment, furnaces and procedure used for annealing of sheet and strip, and of wire, and for the double heat-treatment of precipitation-hardenable alloys, are considered. Consideration of inspection procedure covers methods used for detection of internal defects, and pickling and etching procedures employed for revelation of surface defects. Process testing of alloys for use in applications involving specialized physical properties is of considerable significance in the nickel-base alloy groups: techniques described in this connexion include welding tests applied, respectively, to nickel-chromium valve-coating alloy and to nickel-chromium-iron alloy for heater sheaths; a spiralling test used on heater-gauge nickel-chromium electrical-resistance wire; a test made to determine the gas content of 'gas-free' nickel for radio-valve parts, and a plating test to which nickel anodes are subjected.

Some account is also given of methods used for assessment of special physical and mechanical properties essential in some types of nickel-containing alloy, e.g., (i) tests applied to high-permeability nickel-iron-base alloys; (ii) methods for ensuring the close range of coefficient of thermal expansion required in thermostatic materials, alloys used in glass-to-metal seals, and other applications, (iii) electrical tests for wire and tape; (iv) tests applied to materials to be used in thermocouples; (v) life testing of electrical-heating elements, and (vi) methods of creep testing applied to alloys of the types used in aircraft gas turbines and other components for high-temperature service.

Reference is also made to precautions observed in packaging and dispatch, with special reference to packaging of wires of various gauges.

Constitutional Studies on Alloy Systems: Bibliography

H. SPENGLER: 'History and Present Position of Research on the Constitution of Metals and Alloys. Part IV.' *Metall*, 1954, vol. 8, Dec., p. 955.

For reference to earlier sections of this review see *Nickel Bulletin*, 1954, vol. 27, Nos. 7-8 and 12, pp. 130 and 226.

The present instalment gives reference to literature

on the constitution of quaternary and more complex systems. Nickel-containing alloys mentioned are the following:—

Nickel–silver–gold–copper
„ –silver–copper–zinc
„ –aluminium–cobalt–iron
„ –aluminium–copper–iron
„ –aluminium–copper–magnesium
„ –aluminium–copper–zinc
„ –aluminium–magnesium–zinc
„ –cobalt–chromium–iron
„ –cobalt–iron–manganese
„ –cobalt–iron–titanium
„ –chromium–iron–nitrogen
„ –chromium–iron–vanadium
„ –copper–iron–manganese
„ –copper–magnesium–zinc

Materials for Handling Hydrofluoric Acid

See abstract on p. 79.

Chemical and Electrochemical Polishing of Metals and Alloys: Patent Literature

See abstract on p. 58.

Polarization of Nickel and Nickel-Copper Alloys in Sodium-Chloride Solutions

See abstract on p. 59.

Overlaying of Steel and Cast Iron with High-Nickel Alloys

See abstract on p. 77.

NICKEL-IRON ALLOYS

Transformations in Nickel-Iron Alloys

F. LIHL: 'Transformation Ranges in the Iron-Nickel System in the Temperature Range below 300°C.' *Archiv f.d. Eisenhüttenwesen*, 1954, vol. 25, Sept.-Oct., pp. 475–8.

The author discusses the complications inherent in study of the iron-nickel system, due to the slow rate of the $\gamma \rightleftharpoons \alpha$ transformation and the difficulty of establishing equilibrium conditions. He outlines the limitations associated with the use of alloy powders produced by reduction of appropriate compounds (e.g., the formates) of the two metals, and advocates the use of alloys prepared by amalgamation. The underlying principles of the amalgamation procedure are described. Using this method, alloys covering the whole range of the nickel-iron system were prepared and were examined by X-ray methods. The saturation concentration of the α solid solution was found to be at 9·5 at.-per cent. of nickel, and the saturation limit for the γ solution lies at 66 at. per cent. nickel. These conclusions agree well with the equilibrium diagram set up by E. A. OWEN and Y. H. LIU for a temperature just below 250°C. This close agreement is taken as demonstrating not only the accuracy of the conclusions with regard to the features of the equilibrium diagram, but also as an indication of the ability of the amalgamation method of preparation to ensure equilibrium conditions. It is urged that it should be more widely used for study of alloy systems at temperatures below 300°C.

Phase Diagram for Carbon-containing Nickel-Iron Alloys

P. SAMUEL, L. G. FINCH and J. R. RAIT: 'A Phase Diagram for 1 per cent. Carbon-Iron Alloys containing up to 16 per cent. Nickel.' *Nature*, 1955, vol. 175, Jan. 1, pp. 37–8.

This note describes work done in connexion with study of austenite-stabilization phenomena in iron-nickel alloys containing 1 per cent. of carbon.

Ingots of 18-lb. weight, poured from steel prepared in a high-frequency furnace, were forged to rods of $\frac{5}{16}$-in. diameter, and these were normalized from 1050°C. Specimens were machined, nickel-plated, and tempered for 24 hours at 600°C. before testing. The progress of transformation was determined dilatometrically, readings being taken at 5°C. intervals, with a heating rate of 1°C. per minute.

The results, which are shown in the note, agree closely with the 1 per cent. carbon section which may be derived from a ternary diagram based on the assumption of carbide stability: the figure does not take into account the presence of graphite, but the presence of graphite was also investigated. Its presence was observed in alloys containing 5 per cent. or more of nickel, but the amount was not appreciable except in the higher-nickel compositions. Such alloys showed increase in retained austenite when quenched from temperatures above those at which all the carbides were in solution. Determination of the graphite content of a 15·8 per cent. nickel alloy, after quenching from various temperatures, indicated rapidly increasing solubility of graphite with rising temperature of treatment. It is suggested that in alloys containing more than 5 per cent. of nickel there is a graphite-solubility line above, and roughly parallel to, the carbide line. Pronounced depression of the austenite-ferrite transformation on cooling is a characteristic feature of these alloys, and the writers point out that the diagram presented is not generally applicable to transformations on cooling.

Constitutional Studies on Alloy Systems: Bibliography

See abstract on p. 63.

Segregation of Silicon in Nickel-Iron-base Alloys

R. E. S. WALTERS: 'Equilibrium Segregation of Silicon at Grain Boundaries in Nickel-Iron-Copper-Molybdenum Alloys.' *Acta Metallurgica*, 1954, vol. 2, Nov., pp. 890–3.

The writer reports observations on alloys containing nickel 77, iron 14, copper 5, molybdenum 4, per cent., with silicon ranging from 0·01 to 0·03 per cent.

The specimens (the structures of which are illustrated in the original) were prepared by both chemical and electrolytic polishing, under standard conditions.

The first evidence of equilibrium segregation was found in specimens annealed in pure hydrogen at 1050°C. for three hours, and furnace cooled. Intensity of etching increased with rise in silicon content, and within any one particular specimen varied from one grain boundary to another, a feature which is illustrated. By heating specimens in this condition for ten minutes at 800°C., and quenching in hydrogen, the segregation effects were to a large extent, but not entirely, suppressed: quenching from 700°C. was not effective. After partial suppression by the 800°C. treatment, segregation recurred on heating at 600°C.: in a specimen containing 0·02 per cent. of silicon it could be detected after twenty minutes, and was pronounced after one hour at that temperature.

The writer suggests that the observations can be explained by assuming that the equilibrium concentration of silicon is higher at the boundaries than in the crystals, especially at temperatures below 800°C. The nature of the etching suggests that the concentration of silicon at a boundary depends on the disorientation between the grains meeting at the boundary.

Magnetic Materials: Properties and Uses

M. G. SAY (Editor): 'Magnetic Alloys and Ferrites.' *Published by George Newnes, Ltd., London*, 1954; 196 pp. + index. Price 21/-.

It is pointed out in the preface that within recent years many developments of importance have taken place in magnetic materials: established materials have been improved and new types evolved. Full utilization of the properties of the new materials calls for an intimate knowledge of their characteristics and of their technological capabilities. The object of this book, which combines the theoretical with the practical approach, is to provide the information required.

The individual chapters are written by specialists in the respective aspects of the subject: the scope of the individual contributions is indicated below:—

F. BRAILSFORD: 'Ferromagnetic Theory', pp. 1–36.

W. S. MELVILLE: 'Soft Magnetic Materials', pp. 37–84;
'Magnetically-Soft Ferrites', pp. 85–94.

F. KNIGHT: 'Permanent-Magnet Steels and Alloys', pp. 95–143;
'Micropowder Magnets', pp. 144–7.

B. W. ST. LEGER MONTAGUE: 'Permanent-Magnet Ferrites', pp. 148–58.

C. GORDON SMITH: 'Magnetic Powder Cores', pp. 159–70;
'Non-Magnetic Ferrous and Magnetic Compensating Alloys', pp. 171–8;
'Magnetic Recording Materials', pp. 179–83;
'Magnetostrictive Materials', pp. 184–9.

Appendix

M. G. SAY: 'Introduction to M.K.S. Magnetic Units', pp. 190–6.

The book is fully illustrated, and each chapter is provided with a selected *bibliography* of relevant literature.

Magnetic Properties of Evaporated Nickel Films

M. S. BLOIS: 'Vacuum Deposition of Magnetic Alloy Films.' *Bull. Amer. Physical Soc.*, 1954, vol. 29, Dec. 28, p. 33.
Abstract of paper presented to American Physical Society Winter Meeting, December, 1954.

Films of iron-nickel and iron-cobalt alloys, ranging in thickness from 1,000Å to 50,000Å, were deposited by vacuum evaporation, and the coercivity, saturation induction, and hysteresis-loop form of the alloy films were determined. Changes in alloy composition occurring between the melting of the starting materials and final formation of the films were studied and are to be compared with behaviour which would be predicted on the basis of current theory. It was observed that a ferromagnetic film formed by vacuum deposition under the influence of a magnetic field shows directional properties dependent on the field: it was found possible so to produce Permalloy films characterized by square hysteresis loops. The general indication from the author's results is that films deposited by vacuum evaporation have properties similar to those of the bulk alloy, except that the coercive force of the films is consistently higher than that of the bulk material.

Magnetostriction in Cobalt-Nickel-Iron Alloys

H. E. STAUSS and G. SANDOZ: 'Linear Magnetostriction of Some Ternary Cobalt-Iron-Nickel Alloys.' *Bull. Amer. Physical Soc.*, 1954, vol. 29, Dec. 28, p. 23.

Abstract of paper presented to American Physical Society, Winter Meeting, December, 1954.

The measurements reported were made on ternary alloys of high cobalt content. In most cases the linear magnetostrictions observed at the highest magnetic inductions attained (approximately saturation magnetostrictions) were less than the published values of saturation magnetostriction for binary cobalt-iron alloys of similar cobalt content. In the restricted range of composition from 45 to 60 per cent. cobalt the substitution of about 5 per cent. or less of nickel for iron appeared to result in small increases of magnetostriction (up to about 10 per cent.), as compared with binary alloys of similar cobalt content. No magnetostriction values found for the ternary alloys were greater than some which have been recorded in the literature for binary cobalt-iron alloys. The authors give data on change of magnetostriction with magnetic induction, for the ternary alloys studied

Fabrication of Nickel-Iron and Other High-Permeability Alloys: American Practice

'Fabrication of High-Permeability Magnetic Materials.' *Engineer*, 1955, vol. 199, Feb. 25, pp. 285-8.

In the U.S.A., as in other countries, developments in magnetic materials have been among the most spectacular advances in physical metallurgy during the past fifty years, and the utilization of such materials in a constantly expanding range of applications has created a demand for equipment by which they can be fabricated to many new forms. This article is a review of some of the processes currently being used by American manufacturers of magnetic laminations and cores. The special properties required in alloys for various uses are discussed, and rolling, slitting, and roller-levelling equipment is described and illustrated. The operations discussed are exemplified by reference to their use on nickel-iron-base alloys of many types, and other high-permeability materials.

CAST IRON

Thermal Stability of Spheroidal-Graphite Irons

H. TIMMERBEIL: 'Thermal Stability of Spheroidal-Graphite Iron.' 21*st International Foundry Congress*, 1954, *Paper No.* 34; 5 pp.

The author discusses the stability, at elevated temperatures, of flake-graphite cast iron, and refers to the well known advantage of raising silicon to 6 per cent., in giving marked improvement in stability and heat-resistance at temperatures up to 800°C. Further improved resistance is provided by addition of 4 per cent. of aluminium, in association with the 6 per cent. of silicon.

The paper includes detailed results of studies of the heat-resistance of S.G. iron having a range of silicon contents. It is shown that S.G. iron has better heat-resisting qualities than the corresponding flake-graphite iron, and that S.G. iron containing 6·4 per cent. of silicon is stable up to 1000°C. The author finds that nickel, introduced in the nickel-magnesium addition alloy, enhances thermal stability.

Impact Characteristics of Spheroidal-Graphite Cast Irons

G. N. J. GILBERT: 'Ductile and Brittle Fracture in Ferritic Nodular Irons (Nickel-Magnesium Type).' Paper presented at 1953 Symposium on 'Effect of Temperature on the Brittle Behaviour of Metals, with particular reference to Low Temperatures.' Contained in *Amer. Soc. Testing Materials Special Tech. Publn. No.* 158, 1954, pp. 415-31.

The author reports an investigation of the mechanism of failure of ferritic S.G. iron in impact tests, using notched and un-notched test pieces. The results are compared with failures in slow-bend tests.

The conclusions drawn with regard to the influence of composition on impact-transition temperatures confirm the work of previous authors. Silicon and phosphorus raise the temperature of transition from brittle to ductile fracture. In a low-phosphorus iron silicon must not exceed about 2·4 per cent., and if phosphorus is higher than 0·08 per cent. silicon should be below the 2·4 per cent. level. At 0·16 per cent. phosphorus the silicon must be kept below 2·0 per cent. if a fully tough fracture is to be obtained. The author differentiates between the energies involved in (*a*) crack initiation, and (*b*) crack propagation, and shows that these values are subject to separate transition with varying temperature. Energy involved in crack propagation has the higher temperature of transition: this explains the higher transition temperature found for notched specimens, since the notched-bar impact test measures mainly the energy required for propagation rather than initiation of the crack.

Austenitic Spheroidal-Graphite Cast Irons

J. GRILLIAT: 'Study of Some Spheroidal-Graphite Austenitic Cast Irons.'
21*st International Foundry Congress*, 1954, *Paper No.* 36; 11 pp.

The author reports laboratory studies of various austenitic S.G. irons, the compositions of which were selected on the basis of well-established types of flake-graphite Ni-Resist. The irons examined included casts containing nickel 16–20, copper 0-4, silicon up to 4·25, chromium up to 1·4, per cent., and a special low-expansion cast iron containing 33 per cent. of nickel.

The austenitic cast irons showed tensile strengths varying from 25 to 35 tons per sq. in., with elastic limits (0·2 per cent. proof stress) of 14–20 tons per sq. in., and elongations of 11–25 per cent. The best combination of properties was obtained with a composition of nickel 17·26, copper 3·9, chromium 1·1, per cent.: such an iron gave a tensile strength of 35 tons per sq. in., elastic limit 19 tons per sq. in., and 25 per cent. elongation. Tensile strength and elongation were somewhat raised by homogenizing at 1000°C. and 1075°C.: the elastic limit was generally lowered by such treatment. Brinell hardness of the irons ranged from 135 to 172.

In discussing composition, the author emphasizes that magnesium is a powerful carbide-stabilizer, and that this fact limits the amount of chromium which can be present in S.G. irons, particularly since the carbides formed with magnesium and chromium are very stable and are difficult to break down by heat-treatment. Observations on the influence of copper content confirm that in S.G. irons this element must be restricted to less than 4 per cent. The presence of carbides has a markedly deleterious effect on resistance to shock, and copper also adversely affects this property.

Investigation of certain physical properties is also recorded: it is noted that the electrical resistivity of the austenitic S.G. irons, at 97–107 c.g.s. units, is appreciably lower than that of flake-graphite austenitic irons. The coefficient of thermal expansion is, however, similar to that of flake-graphite irons of corresponding compositions. Tests of heat-resistance confirmed the superiority of S.G. irons in this respect.

High-Temperature Properties of S.G. Iron

C. R. WILKS, N. A. MATTHEWS and R. W. KRAFT: 'Elevated-Temperature Properties of Ductile Cast Iron.' *Trans. Amer. Soc. Metals*, 1954, vol. 47, Preprint 34; 21 pp.

This paper presents creep and stress-rupture data, results of room-temperature and elevated-temperature tensile tests, and growth data, for three types of S.G. iron:—ferritic (annealed), pearlitic (normalized) and austenitic (as-cast). For the ferritic and pearlitic irons the creep, stress-rupture and growth tests were made over the range 425°-650°C. and for the austenitic iron at temperatures up to 760°C. On all three types short-time tensile tests were made up to 760°C. Mechanical properties were determined also on bars which had undergone long-term creep tests terminated before fracture, and microstructural changes occurring during creep were studied.

A full account of test procedure, together with results of the individual series of tests, will be found in the original. From the observations made the authors draw the following conclusions:—

'The short-term tensile and rupture properties of pearlitic ductile iron are superior to those of the ferritic grades. Correspondingly superior creep properties, reflecting long-term behaviour, hold only to about 800°F. (425°C.). At higher temperatures, the potential long-term superiority cannot be realized, as the pearlitic iron, structurally unstable, progressively graphitizes and reverts to a ferritic iron which has lower creep strength than the standard ferritic grade. From 800° to 1200°F. (425° to 650°C.) creep strength of the stable ferritic iron is comparable to that of low-carbon steel.

'The austenitic iron is markedly stronger at and above 1000°F. (540°C.) than the ferritic and pearlitic grades, which lose strength rapidly above 800°F. (425°C.).

'Utility of the standard ferritic and pearlitic grades appears limited to a maximum temperature of 1000°-1100°F. (540°-595°C.) for long-term load-carrying applications, when both scaling-resistance and strength are considered. The high-nickel austenitic iron should have similar utility up to 1200° or 1300°F. (650° or 705°C.).'

S.G. Iron for Crankshafts

L. MARTINAGLIA: 'Spheroidal-Graphite or Nodular-Graphite Cast Iron as an Engineering Material.' *Paper to 21st International Foundry Congress*, 1954; 6 pp.

The author opens with a brief summary of the nature and properties of S.G. iron, as indicating its significance in the engineering field. This survey is followed by more detailed consideration of the dynamic properties of the material, particularly under complex stresses. Curves show endurance in rotating-beam tests, in torsion tests, and under complex bending and torsion, all of which properties are relevant to behaviour of crankshaft materials. Crankshaft design which utilizes the properties of S.G. iron to best advantage is illustrated, and the suitability of this material for other engineering components, e.g., Diesel-engine frames, gear boxes, etc., is urged, as making possible simplification of design and reduction in weight.

'S.G. Iron Crankshafts in the New Ford 'Taunus' Car.' *Autocar*, 1955, vol. 102, Jan. 14. p. 43.

Details have recently been given, by the German Ford Motor Company, of the crankshaft used in the Taunus 15-M car, which replaces the 12-M model. The shaft, the design of which is illustrated in this article, is of S.G. iron.

CONSTRUCTIONAL STEELS

Effect of Pouring Conditions on Structure of Steel Ingots

BRIT. IRON AND STEEL RESEARCH ASSOCN., INGOTS COMMITTEE: 'Effect of Temperature and Pouring Speed on Ingot Structure.'
Jnl. Iron and Steel Inst., 1955, vol. 179, Feb., pp. 120-3.

The investigation reported was made on a 5-ton high-frequency melt of low-carbon case-hardening steel (to Specification B.S. En 36) containing nickel 3, chromium 1, per cent. It was tapped in two halves, having a temperature difference of 40°C. between them. Each half was made to produce two 1-ton ingots, which were cast at different rates.

The surface of the ingot cast more rapidly, at higher temperature, showed transverse cracks; that of the more slowly cast ingot, poured at a lower temperature, was slaggy. Longitudinal sections of the ingots showed only small differences in structure: as was anticipated, the length of the columnar crystals in the ingots cast at the higher temperature were somewhat longer. Particular attention is directed to the structure observed on etching with ammonium persulphate, which is not accepted as being representative of the as-cast structure. A theory is put forward that it is the result of the peritectic transformation in the particular steel studied.

Influence of Vanadium on Transformations in Case-Hardening Nickel-Chromium Steel

S. AMMARELLER and P. OPEL: 'Acceleration of the Austenite-Pearlite Transformation in a 2-2 per cent. Nickel-Chromium Case-Hardening Steel, by Additions of Vanadium.' *Stahl und Eisen*, 1955, vol. 75, Jan. 27, 65-9.

Time-temperature-transformation studies on a case-hardening nickel-chromium steel to D.I.N. specification 17210, grade 18 CrNi 8 (containing 2 per cent. each of nickel and chromium, with 0·15 per cent. of carbon) have shown that the austenite-pearlite transformation can be markedly accelerated by additions of vanadium, of the order of 0·1 per cent. In

some cases this has advantages with regard to the rate of cooling which is permissible after hardening. The mechanical properties of the steels so modified satisfactorily meet the requirements of the specification, provided that the carbon content of the vanadium-containing steels is raised from the 0·17 level to 0·22 per cent., to compensate for the carbon which combines with the vanadium.

In discussion, H. KIESSLER emphasized the suitability of the nickel-chromium steel for case-hardened parts. E. KUNZE reported confirmatory experience with vanadium additions, and stated that similar accelerating effects had been observed with steels of the same type modified by small amounts of niobium or titanium.

(In connexion with this paper see also Belgian Patent 531,268, abstracted on p. 81.)

Phase Diagram for Carbon-containing Nickel-Iron Alloys

See abstract on p. 64.

Low-Alloy Nickel-Chromium-Molybdenum Steel

J. B. CAMPBELL: 'New Tough High-Strength Steel Cuts Fabrication Cost.' *Materials and Methods*, 1955, vol. 41, Jan., pp. 102–6.

The article describes the properties of a low-alloy plate steel of which the following is a typical composition: carbon 0·15, silicon 0·24, manganese 0·75, sulphur 0·030, phosphorus 0·026, nickel 0·85, chromium 0·50, molybdenum 0·45, vanadium 0·05, copper 0·31, boron 0·0029, per cent., iron remainder. Minimum tensile strength of the steel is given as 105,000 p.s.i. (47 tons per sq. in.), with minimum yield strength of 90,000 p.s.i. (40 tons per sq. in.). Although normally supplied in the form of quenched and tempered plate, the steel is obtainable also as hot-rolled bar, semi-finished products, or forgings. Its good resistance to wear, and satisfactory resistance to impact over a considerable range of temperature, make the steel suitable for such applications as power shovels, parts of steam hammers, and other equipment subject to heavy abrasion and severe service. The welding qualities of the steel are a further advantage: stress-relieving is usually not required. Typical tests on welded plate are recorded. Bursting and other tests indicate its suitability for fabrication of pressure vessels, and a number of other potential uses are suggested. Maximum service temperature suitable for this steel is of the order of 900°F. (480°C.): some elevated-temperature data are shown in this article. On the basis of 18-month exposure tests, the resistance of the steel to atmospheric exposure is estimated as being at least four times that of carbon steel.

Chemical and Electrochemical Polishing of Metals and Alloys: Patent Literature

See abstract on p. 58.

Spot Welding of Hardenable Carbon and Low-Alloy Steels

H. E. DIXON: 'Spot Welding of Hardenable Steels. A Review of Information published up to June, 1954.' *Brit. Welding Jnl.*, 1955, vol. 2, Mar., pp. 121–33. Report issued under the aegis of the British Welding Research Association.

The effect of thickness of sheet and composition of the steel is considered in relation to spot welds in carbon and low-alloy steels. It is shown that the rapid chilling associated with the single-impulse welding cycle may result in either a tough or a brittle weld, depending on the carbon content of the steel and the thickness of the sheet welded. Weld ductility may be improved by a full quench-and-temper treatment, which can be carried out as an integral part of the welding cycle, in a suitably equipped spot-welding machine. Recommendations are made with regard to optimum welding conditions, and an appraisal of weld-test methods is included in the survey. The review, which was prepared as a preliminary to a fundamental investigation of the subject, is based on literature to which reference is given in a *bibliography* of 24 items. Much of the information is from American sources. The sections relating to low-alloy steels include a considerable amount of data on nickel-containing types of steel.

HEAT- AND CORROSION-RESISTING MATERIALS

Influence of Structure on Creep-Resistance of Austenitic Nickel-Chromium Steels

K. BUNGARDT and H. SYCHROVSKY: 'Relation between Structure and Creep Characteristics of Austenitic Chromium-Molybdenum-Nickel Steels.' *Stahl und Eisen*, 1955, vol. 75, Jan. 13, pp. 25–39.

The authors briefly review some of the outstanding literature relevant to the influence of structure on high-temperature behaviour, drawing attention to studies which have been made of the effects of molybdenum, niobium and other elements, and to the significance of sigma phase formed under prolonged exposure at high temperatures.

It is concluded that investigations to date do not permit clear conclusions with regard to the influence of alloy elements. The work reported in this paper was directed towards elucidating some of the outstanding uncertainties.

The tests described were made on two series of steels, containing, respectively, chromium 16, with nickel 13, per cent., and chromium 16, with nickel 16, per cent., to both of which molybdenum was added in amounts up to 2·6 per cent., and niobium-tantalum up to 2·73 per cent.

The ingots of high-frequency steels of these types were forged to 26-mm. diameter bar, which was heat-treated by three methods:—

(1) Heated for ¼ hour at 1100°C.; water quenched.

(2) Heated for ¼ hour at 1100°C.; water-quenched, and re-heated for 2 hours at 875°C.; air-cooled.

(3) Heated for ¼ hour at 1100°C.; water-quenched, drawn to 12–15 per cent. reduction at room temperature.

Condition 1 corresponds to the usual heat-treatment, which, in non-stabilized steels, results in homogeneous solid solution. When niobium is present a niobium carbide is formed, provided that the niobium:carbon ratio is in the stoichiometric proportion. Heating at 875°C. (treatment 2), i.e., at a temperature slightly below that at which the carbides go into solution, was designed to determine whether, by prior elimination of precipitates, it is possible to ensure a certain stability of structure. Condition 3, corresponding to one often used to secure creep-resistance, was included to reveal the extent to which the strengthening achieved by cold work is permanently useful, and to ascertain the effect of accelerated precipitation and associated embrittlement.

The steels were subjected, in various conditions, to (*a*) metallographic and X-ray examination; (*b*) determination of embrittlement (at elevated and at room temperatures) after prolonged heating at 600°, 700° and 800°C. without applied stress; (*c*) creep tests and tests of susceptibility to elevated-temperature embrittlement when heated for prolonged periods at 650°C. under load.

In support of the metallographic examination, magnetic-saturation measurements were made to determine delta-ferrite content. Full details of all experimental conditions and results are recorded in the paper, which is illustrated by many tables, graphs and photomicrographs. The authors summarize their findings as follows:—

Neither in the as-quenched condition nor after re-heating at the temperatures used does the presence of molybdenum up to 2·6 per cent. lead to formation of a characteristic molybdenum phase. The molybdenum, which is in solution in the steel after quenching, participates, on annealing, in formation of sigma phase and apparently also replaces niobium in the compound Fe_3Nb_2. After quenching at temperatures up to 1350°C. the greater proportion of the niobium is still undissolved, and is present as niobium carbide (NbC): when the ratio of niobium to carbon only slightly exceeds about 10:1 it is combined as the intermetallic compound Fe_3Nb_2. Annealing results in precipitation of the niobium carbide and iron carbide which are in solution on quenching. No marked influence of niobium on rate of sigma-phase formation was observed. At temperatures above 600°C. both the iron niobide and the sigma phase show a tendency to agglomerate; the diffusion rate of the niobium carbide, is, however, the slower. Raising the nickel content from 13 to 16 per cent. lessened precipitation of all types, slowed down the rates of diffusion, and enlarged the gamma region even at high quenching temperatures. Formation of sigma phase is not contingent on prior or simultaneous formation of ferrite: it can form direct from austenite.

Toughness in the quenched condition is substantially unaffected by the presence of molybdenum, but niobium additions, in the amounts required to combine the carbon, lower the toughness. Raising the carbon content, for a given niobium:carbon ratio, has a similar effect. Susceptibility to room-temperature embrittlement after heating at 600°–800°C. is more severely affected by molybdenum than by niobium, but the reverse effect is observed with regard to embrittlement at elevated temperatures. Heating for two hours at 875°C. after quenching was practically without effect on toughness in the initial condition. Such treatment did not prevent precipitation in subsequent long-time annealing, and it was therefore without significant influence on the mechanical properties of the steels.

Increasing molybdenum and niobium contents caused increased capacity for strengthening in the quenched steels. Cold-working accelerates precipitation on annealing, so that annealing of a cold-worked steel at 600°C. results in marked fall in toughness at room temperature. Recovery and recrystallization occurred on heating at 700°C., and this change was even more clearly marked at 800°C.: the higher the molybdenum content of the steel the higher is the temperature required to produce these effects. Cold-working can be advantageously used to enhance the creep-resistance of such steels at temperatures not exceeding 650°C.

Strength at elevated temperatures is beneficially influenced by molybdenum and by niobium. Niobium, present in the 10×C ratio in a molybdenum-free steel, has a greater effect on creep-resistance than has 2·6 per cent. of molybdenum in a steel containing no niobium. With a given ratio of niobium: carbon of about 10:1 addition of molybdenum further raises the creep strength: in a steel containing nickel 13, chromium 16, per cent. the preferred molybdenum content is 1·5 per cent., whereas in a 16 per cent. nickel, 16 per cent. chromium steel, best results are obtained with 2 per cent. of molybdenum. Excess niobium, in any considerable amount, has a markedly deleterious influence on creep strength, resulting from increased precipitation of iron niobide and the strong tendency of that compound to segregate.

All the steels examined showed normal creep behaviour, but the authors call attention to the early commencement of tertiary creep in the 13 per cent. nickel, 16 per cent. chromium series: it began before half the total life had elapsed, whereas in the 16–16 nickel-chromium steel tertiary creep set in only at about half way through total life, or at an even later stage.

Relationships between Long- and Short-Time Properties in Nickel-Chromium-base Alloys

A. GRAHAM and K. F. A. WALLES: 'Relationships between Long- and Short-Time Creep and Tensile Properties of a Commercial Alloy.'
Jnl. Iron and Steel Inst., 1955, vol. 179, Feb., pp. 105–20.

The paper describes experiments made to guide the development of a theory of deformation, the material used for establishing the respective interrelations of properties being the high-temperature

alloy Nimonic 80, for which, in addition to the properties established by the authors' tests, supplementary data were available for correlation. Experimental results are recorded for short-time creep tests, two forms of tension tests, and creep-recovery tests, on the nickel-chromium-base alloy used, and comparisons are made of these data with long-time creep behaviour of other specimens of Nimonic 80-type alloys.

The theory of deformation developed is claimed to meet a variety of requirements, and is believed to be applicable to a wide range of materials: the conclusion is drawn that there may be much greater uniformity in the behaviour of different materials than is generally supposed.

Iron-base High-Temperature Casting Alloy

W. SIEGFRIED and F. EISERMANN: 'A Turbine-Blade Alloy Castable and Low in Cobalt and Niobium.' *Metal Progress*, 1955, vol. 67, Jan., pp. 141–6.

The authors report experiments carried out in the works of Sulzer Brothers, Winterthur, Switzerland, in development of a casting alloy which should be suitable for the blading of gas turbines, but be low in content of expensive metals, especially cobalt and niobium.

Starting from an iron-base alloy containing nickel 25, chromium 18, per cent., modifications were made, by additions of varying percentages of carbon, tungsten, vanadium, molybdenum and niobium. This led to selection of a preferred matrix base, and as a result of tests on various modifications of it, the following composition was arrived at: carbon 0·1, chromium 18, nickel 17, manganese 4, cobalt 4, niobium 1, tungsten 2, molybdenum 3, nitrogen 0·2, per cent., iron balance. Creep, stress-rupture, thermal-shock and other tests on this alloy are reported, and the behaviour of cast blading made from it is compared with that of blading of standard wrought and cast alloys.

Formation of Sigma in Molybdenum-containing Austenitic Steels

F. BRAUMANN and H. KRÄCHTER: 'The Mechanism of Formation of Sigma Phase in Steel containing Chromium 18, Molybdenum 2, Nickel 10, per cent.' *Archiv f.d. Eisenhüttenwesen*, 1954, vol. 25, Sept.-Oct., pp. 479–86; disc., pp. 486–8.

The work reported is a continuation of that described *ibid.*, 1953, vol. 24, Mar.-Apr., pp. 113–24 (*Nickel Bulletin*, 1953, vol. 26, No. 6, pp. 100–1). The composition of the steel used is given as carbon 0·10, silicon 0·51, manganese 0·49, sulphur 0·018, phosphorus 0·025, chromium 17·4, nickel 9·6, molybdenum 2·6, titanium 0·57, per cent. In order to obtain measurable and varying amounts of ferrite, specimens of the steel were heated (*a*) for 2 hours at 1300°C., and (*b*) for 6 hours at 1100°C. In each case the specimens were water-quenched. The 1300°C. treatment resulted in the presence of some 35 per cent. of ferrite: the 1100°C. treatment gave about 7 per cent. ferrite. Temperature of annealing for production of sigma was 800°C., and the times of heating at that temperature ranged from 5 minutes to 192 hours. Saturation-magnetization measurements and metallographic examination were used to determine the course of sigma-phase formation. In a further series of tests, cold reduction of 70 per cent. was interposed between treatments at 1300° or 1000°C. and re-heating at 800°C.

The observations made are recorded in detail, with tabular and graphical data, and typical photomicrographs of the steels in various conditions are included.

The results show that the ferritic constituent resulting from heating at temperatures above 1000°C. decomposes at 800°C. according to the equation ferrite = sigma phase + austenite, i.e., by a eutectoid reaction, and that after sufficiently long times of heating at 800°C. sigma also precipitates from the austenite solid solution. As was anticipated, cold-working prior to annealing accelerated formation of sigma.

It is shown that the ferrite transformation occurring in this steel is akin to the austenite transformation in unalloyed steels. In the austenitic steels the ferrite assumes the part of the transformable austenite of the unalloyed steels, and the sigma phase takes the place of the carbides. The authors established the T.T.T. curve for isothermal transformation in the steel studied.

In discussion, E. KUNZE and E. HORN described studies of sigma formation in a steel containing carbon 0·45, chromium 23, molybdenum 3, nickel 5, per cent., and demonstrated the suitability of heat-tinting technique for examination of structure.

Dry Corrosion: Practical Problems

L. B. PFEIL: 'Metallurgical Aspects of Dry Corrosion.' Reprint from *Chemistry and Industry*, 1955, Feb. 26, pp. 208–218.

Corrosion Group Spring Lecture, delivered to the Corrosion Group of the Society of Chemical Industry, January 20, 1954.

The introduction to the lecture comprises a highly condensed survey of some of the outstanding theoretical work in the field of dry corrosion: chief attention is given to the difficulties which hinder a full theoretical interpretation of important high-temperature effects on heat-resisting alloys, and to discussion of the lines along which theoretical and practical knowledge may advance.

A review is made of the main groups of commercially important alloys, with specific reference to their high-temperature corrosion-resisting qualities. This survey leads to the conclusion that alloys which can be expected to show satisfactory behaviour at high temperatures must be based mainly on the systems iron-chromium, cobalt-chromium or nickel-chromium. The respective advantages and limitations of these basic types are considered, and the extent to which their intrinsic qualities can be enhanced by addition of other elements is indicated. Particular

attention is given to alloys containing large amounts of nickel and chromium, with or without varying amounts of iron. The decisive influence of trace elements, in determining high-temperature behaviour, is emphasized.

It is pointed out that, in practice, resistance to high-temperature corrosion is seldom the only requirement, and in this connexion attention is directed to the call for improved mechanical properties and creep-resistance, often necessitating the development of highly complex alloys, and thus introducing factors which complicate the application of theoretical principles to calculation of dry-corrosion resistance.

The final section of the lecture comprises a discussion of some of the difficulties arising from the varied and frequently uncontrollable nature of the corrosive media to which high-temperature alloys are exposed. Attack occurring in sulphur-bearing atmospheres, the phenomenon designated 'green rot', and the nature of the corrosion resulting from the products of combustion of certain grades of residual oils are considered as typical problems. Representative examples of the respective forms of attack are illustrated, and means which have been adopted for minimizing corrosion from the various sources are indicated.

In connexion with effects occurring on repeated heating and cooling, and the important influence of scale adhesion, attention is directed to improvements in commercial nickel-chromium electrical-resistance heating wires which have resulted from laboratory study of the influence of trace elements on adhesion of scale.

With regard to future developments, it is urged that, in attempting to narrow the gulf between empirical knowledge of the service behaviour of high-temperature materials and the more fundamental theory of the subject, it will be essential to make the fullest possible use of the theoretical foundations already available. To this end there is need for further data of a type which will allow the extension of established principles to more complex alloys and conditions, and will permit of allowances being made for factors likely to alter practical interpretations which have been based on incomplete fundamental data. The further development of materials which can withstand oxidation or other high-temperature corrosion effects will also depend, to a vital extent, on closer knowledge of the composition and structure of the protective films of corrosion products formed under various conditions. Some of the techniques which may yield information on one or more aspects of dry corrosion are briefly suggested.

The Aircraft Gas Turbine: Materials and Fabrication Methods

K. T. FULTON: 'Production of the Aircraft Turbine Engine.' *Aeroplane*, 1955, vol. 88, Mar. 11, pp. 301-26.

The aim of this informative review is to illustrate the application, in large-scale production, of the principles underlying the development of the aircraft gas turbine. These, the writer considers, are epitomized in the following statement, quoted from a lecture recently given to the Institution of Production Engineers by F. NIXON, Assistant General Manager of Rolls-Royce, Ltd.; 'The aircraft engine is an example of the value of designing for maximum performance, the costly materials and extensive machining being more than repaid by the extra work done by the material, but only where methods of tooling and manufacture have been brought to a high level of efficiency. The result is that the prime cost of the engine . . . is appreciably lower than that of any other engine in its power class.'

The developments which have taken place in this field are considered in five broad sections: blade, disc, casing, ring, and sheet-metal production processes, and the materials used for the respective components. Throughout the review emphasis is placed on the intimate and inevitable relationship between materials, operating conditions, and production processes, and considerable attention is devoted to the materials which have contributed to the spectacular progress achieved during and after the war period. The letterpress is supported by tables showing composition, properties and typical applications of high-temperature alloys, steels and other materials developed or adapted for use in the aircraft engines.

Blades

In connexion with rotor-blading alloys, attention is directed to the outstanding importance of the nickel-chromium-base Nimonic series; milestones of development are traced from the advent of Nimonic 75, in the early stages of the war, to the production of Nimonic 95, and reference is made to the significance of extrusion methods in the fabrication of these alloys. Other alloys of which mention is made in this section include the Jessop G 42 and Firth-Vickers 467 types. The limitations of cast *vs.* wrought blades are briefly discussed. The section on blading materials contains also a discussion of those used for compressor blades, ranging from aluminium alloys to stainless steel, and, most recently, titanium. The advantages and limitations of the respective materials, and their spheres of operation, are reviewed.

Modern methods of forging and machining of blades are described by reference to typical equipment and technique used by representative producers, and some of the exacting inspection methods applied to blading material at various stages are considered.

Attention is next given to turbine nozzle blades, with particular reference to the conditions of thermal shock to which they are subject. The many casting alloys which have been developed for these components include Nimonic-type and other high-nickel-chromium alloys and austenitic steels, representative types of which are named. Reference is also made to improvements recently introduced into precision-investment casting methods, as applied to aircraft-engine components. An account is then given of the development of hollow blades, with particular reference to the extrusion process being operated by Henry Wiggin and Company, Limited. Other improvements which have recently been introduced in the fabrication of high-temperature alloys are also considered, e.g., special brazing techniques, sintering

processes for production of components from powders, porous blades for transpiration cooling, and cermet materials.

Compressor and Turbine Discs

The three materials used for compressor discs (aluminium alloys, various types of ferritic steel, and titanium) are briefly discussed, and more detailed consideration is given to turbine discs, for which a variety of ferritic steels are now in use, following modification in operating conditions which rendered the use of austenitic materials unnecessary. Items of outstanding interest in the fabricating techniques used for these components are noted.

Compressor Casings

Virtually all compressor casings, and related intake, gear, and intermediate casings, are cast. Improved magnesium alloys have been developed to give the freedom from porosity, enhanced creep-resistance and other qualities required; in some engines aluminium alloys are used, and in supersonic engines steel has been introduced. Reference is also made to successful development of spheroidal-graphite cast iron for compressor casings. On the production side, improvements are being made in casting technique and in machining practice.

Circular and Ring Components

The notes under this heading cover components such as turbine-shroud rings, stator rings for retaining compressor, stator, and turbine-nozzle blades, combustion chamber and flame-tube end flanges, the flanges for tailpipes and re-heat systems, and many others. Following the introduction of the Séjournet extrusion process, wrought as well as cast materials are now used for such parts: typical examples of high-nickel alloys and of austenitic and other types of steel are reviewed. For cast ring components the Centri-spinning process is used (with the axis of the machine horizontal or vertical): the differences between the two modifications of the process are noted, and the economic and other advantages of extrusion are reviewed. Attention is called to the rigid inspection methods applied to cast circular components, and some notes are given on recent improvements in cutting technique, e.g., use of carbon dioxide, trichlorethylene, or special oils, as coolants.

Sheet Metal and Other Parts

The main types of component fabricated in sheet metal are the air casings and flame tubes of the combustion system, and exhaust or re-heat systems. These parts operate at very high temperatures, and must thus have adequate high-temperature mechanical properties and be capable of resisting oxidation and thermal shock. Reference is made to the outstanding suitability, for such components, of the nickel-chromium-base alloy Nimonic 75, which is the most popular material for flame tubes, and has the added advantage of good fabricating qualities. A composite material, consisting of a sheet of copper sandwiched between layers of Nimonic 75, has been introduced to give improved thermal conductivity and associated enhanced resistance to thermal shock. Other materials used for flame tubes include various grades of austenitic nickel-chromium steel.

Air-casing conditions, being less arduous, are normally met by mild steel, and where necessary for protection against corrosion the steel is usually nickel-plated, or aluminium-coated.

In general, requirements for jet pipes are similar to those of flame tubes, but are of a lower order, with the exception of those in re-heat systems. Where the conditions are severe the high-nickel alloys are frequently used: in less arduous conditions steels of various types are found satisfactory.

Use of sheet-metal parts in aircraft gas turbines has led to important developments in mechanized welding, spinning and related operations, and other forming techniques: the characteristics of some of the more important of these are reviewed, and passing reference is made to procedures developed for dimpling and welding of stainless steel used in heat-resisting blankets, profile-grinding equipment introduced for use on gears, and precision surface-finishing of pumps used in fuel systems.

Resistance of High-Temperature Alloys to Scaling and Attack by Vanadium Pentoxide

G. T. HARRIS, H. C. CHILD and J. A. KERR: 'Effect of Composition of Gas-Turbine Alloys on Resistance to Scaling and to Vanadium Pentoxide Attack.' *Jnl. Iron and Steel Inst.*, 1955, vol. 179, Mar., pp. 241-8.

The work described is one of the many systematic investigations now under way with a view to determining the metallic materials best suited for use in gas turbines burning residual oils. The main object was two-fold:—

(i) Determination of the scaling-resistance of typical commercially used gas-turbine alloys (austenitic and ferritic) exposed, with or without coatings of vanadium pentoxide, at various temperatures (500°-1200°C., according to the nature of the material tested).

(ii) Study of the effect of composition of austenitic nickel-cobalt-chromium-iron alloys, on resistance to scaling, (*a*) in the uncoated condition, or (*b*) coated with vanadium pentoxide (1·4-1·6 mg./cm².).

(For data on the creep strength of the materials used reference is directed to an earlier paper by the two senior authors.)

The chemical composition of the alloys tested is shown in Table I, p. 73.

(1) *Scaling-Resistance, in Moving Air, with and without a coating of Vanadium Pentoxide*

Behaviour in the temperature range 400°-1200°C. is compared on the basis of behaviour in repeated 70-hour cycles of exposure. For all the materials there is a pronounced increase in scaling attack at some well defined temperature, ranging from just above 600°C. for the ferritic alloys to over 1200°C. for the higher-alloy materials, e.g., R.23 and G.39. For tests of long duration the characteristic temperature is somewhat lower than in shorter exposures. For the vanadium-pentoxide-coated specimens exposure was for 24 hours only. In most cases there

Table I

Alloy	C %	Si %	Ni %	Co %	Cr %	W %	Mo %	V %	Nb %	Ta %
H.31	0·38	0·3	—	—	1·10	—	0·75	—	—	—
H.40	0·22	0·4	0·3	—	2·7	0·5	0·5	0·75	—	—
H.46	0·15	0·4	—	—	11·5	—	0·45	0·3	0·25	—
G.18B	0·4	1·0	13	10	13	2·5	1·8	—	3·0	—
G.19	0·4	1·0	13	10	20	2·5	1·8	—	3·0	—
G.32	0·3	0·3	12	45	19	—	2·0	2·8	1·2	—
G.34	0·8	0·3	12	45	19	—	2·0	2·8	1·2	—
G.39	0·6	1·0	65	—	20	3·0	3·0	—	1·5	1·5
R.20	0·1	0·3	14	—	19	—	—	—	1·7	—
R.22	0·3	1·4	14	—	25	3·0	—	—	—	—
R.23	0·12	1·8	22	—	25	—	—	—	—	—

was a pronounced increase in the scaling attack at about 770°C. The nickel-base alloy G.39 showed the greatest resistance to attack by vanadium pentoxide.

(2) *Effect of Various Addition Elements on Scale-Resistance (at 950° in Moving Air) of an Iron-base Alloy containing Nickel* 20, *Cobalt* 20, *Chromium* 20, *Carbon* 0·5, *per cent.*

The addition elements studied were molybdenum, tungsten, niobium, vanadium and titanium. The only one of these which impaired scaling-resistance was vanadium, which gave rise to formation of vanadium pentoxide in the scale. Particular attention is directed to the fact that high additions of molybdenum proved quite satisfactory, and that the same conclusions held for molybdenum-containing specimens coated with vanadium pentoxide. It is pointed out that most of the evidence which has been advanced (by other investigators) with regard to the deleterious influence of molybdenum, resulting in formation of MoO_3, has been based on 18-8 chromium-nickel steels and other materials less highly alloyed than the material used in the present tests.

(3) *Effect, on Scaling in Air at 950°C., of the Basis Composition of the Alloy*

Study of the influence of the nickel: cobalt: iron ratio of a basis composition containing 20 per cent. of chromium shows little variation in the scaling index with modification of composition in the basis elements. For specimens carrying a vanadium-pentoxide coating, however, an area of low resistance to attack occurs at nickel 25, iron 55, chromium 20, per cent., balance cobalt. The exact extent of this field has not yet been fully established, but repeated experiments have confirmed its existence, and the authors report confirmatory statements from other investigators. In alloys of similar type containing other carbide-forming elements, (3 per cent. of tungsten, molybdenum, or niobium) the area of low resistance is larger, including all alloys containing more than 40 per cent. of iron. The nickel 20, cobalt 20, per cent. composition lies in the area of better resistance, confirming the conclusions drawn in Part 2 with regard to the possibility of using molybdenum in certain types of alloy base. As was to be anticipated, chromium in this group of alloys improved resistance to scaling in air, but with a vanadium-pentoxide coating the improvement effected by chromium is much less.

(4) *Effect of Still Air at 950°C., on Scaling-Resistance of Selected Alloys*

In view of observations made by LESLIE and FONTANA on the susceptibility of some molybdenum-containing alloys to scaling in a static atmosphere, tests were made on the 20-20-20 nickel-cobalt-chromium-iron alloy containing also vanadium, niobium, tungsten, titanium, or molybdenum. The results show that in a molybdenum-containing high-alloy base behaviour in still air is not markedly different from that in moving air, but they confirm the severity of attack of still air on iron-base alloys containing molybdenum and vanadium.

The most important conclusion of the investigation is that for alloys rich in nickel, cobalt, and chromium, additions of molybdenum, tungsten, niobium and titanium have no pronouncedly deleterious effect on scaling-resistance at 950°C., in moving or in still air. The addition of vanadium to such alloys does, however, seriously lower scaling-resistance.

Although none of the alloys studied can be considered satisfactorily resistant to vanadium-pentoxide attack, some are much more resistant than others. In general, such resistance is a function of the base composition, i.e., the nickel: cobalt: chromium ratio,

If the iron content is less than 30 per cent. the alloy will probably be reasonably resistant to vanadium-pentoxide attack provided that:—

(i) The chromium content is at least 16 per cent.
(ii) The vanadium content does not exceed 2 per cent.

The following suggestions, *put forward on a tentative basis only*, are made as likely to be valid for alloys of which the iron content is more than 30 per cent.:—

(i) The chromium content should be at least 16 per cent.
(ii) The nickel content should not lie in the range 10–40 per cent.
(iii) The vanadium content should be less than 0·5 per cent.
(iv) The molybdenum content should be less than 3 per cent.

For many purposes for which these high-temperature alloys are required the use of high-iron compositions would be precluded also on the ground of insufficient strength.

High-Temperature Properties of S.G. Iron

See abstract on p. 67.

Thermal Stability of Spheroidal-Graphite Irons

See abstract on p. 66.

Symposium on Control of Quality in Production of Wrought Non-Ferrous Materials

See abstract on p. 62.

Resistance Sintering of Metal Powders

See abstract on p. 58.

Nickel-Chromium-Boron Brazing Alloy

A. S. ROSE and W. N. LEWIS: 'High-Temperature Alloy Brazing of Thin Materials for Jet Engines.' *Welding Jnl.*, 1955, vol. 34, Jan., pp. 30–9.

This paper deals with the development of a brazing alloy of the following composition, which is classified as A.W.S./A.S.T.M. BNiCr filler material, and, more specifically, as A.M.S. 4775 material.

Composition	%
Chromium	17
Nickel	70
Boron	4
Silicon	4
Iron	4
Carbon	1

The melting range of the alloy, an important factor in connexion with its use as a brazing material, is relatively wide (solidus 1850°F. : 1010°C., liquidus 1950°F. : 1065°C.). In brazing, a temperature of 2100°F. (1150°C.) is generally used.

The alloy has proved successful in brazing of sheet in a wide range of heat-resisting alloys, and of lower-alloy materials. Tests on the joints so made have indicated satisfactory retention of strength at temperatures up to about 1600°F. (870°C.), but certain difficulties have been found in using the alloy for brazing thin materials. The problems arise as a result of its wide melting range, and the marked tendency towards alloying between the brazing alloy and the high-temperature parent materials on which it is used. These difficulties are considered in this paper and recommendations are made for overcoming them.

Effects produced in the brazing of (1) copper, and (2) steel, with the copper-silver eutectic (copper 28, silver 72, per cent.) and with a 50–50 silver-copper alloy are used as a basis for discussion of the problems introduced by the melting range of the nickel-chromium-boron alloy, and the following conditions are laid down as being essential for securing best results:—

(1) rate of heating through the melting range must be rapid;
(2) length of time the parts are held at the brazing temperature must be kept as short as possible;
(3) amount of brazing alloy powder placed at the joint must be kept to a minimum.

A further important factor is that both the brazing material and the parent alloy be protected from contact with an oxidizing atmosphere: brazing should be carried out in a protective atmosphere of deoxidized and dehumidified hydrogen.

The strength of the brazed joints produced in thin materials with the nickel-base alloy is discussed and illustrated, with particular reference to the influence of the extent of penetration of the base by the brazing material: the tensile strength of joints in which severe penetration has occurred is much lower than that in which conditions have been correctly controlled. In the tests reported, tensile sheet specimens 0·025 in. thick were brazed with equivalent amounts of brazing alloy, being held in a furnace at 2200°F. (1205°C.) for 1, 2, 3, 4, 5, 10, 20, 40, 60 or 90 minutes after observation of melting of the brazing alloy. The specimens were metallographically examined, to determine the extent of the attack on the parent sheet, and the strength properties of the joints were evaluated. Analysis of the observations made shows that even with nominal brazing times, e.g., 5 minutes, grain-boundary penetration causes drastic loss of ductility. Such times cause only moderate loss of strength, but as the times are increased, with resultant deeper alloying, greater losses occur. The data all serve to emphasize the importance of minimizing alloying by control of time, temperature, and amount of brazing material used.

Brazing technique is described in detail, with details of the Inconel retorts used, and the layout of the furnace and gas-supply equipment, etc. Application of the brazing material is usually by means of a paste containing the powder alloy and a thermoplastic acrylic resin, in an organic solvent such as toluol, xylol, etc. Following application of the paste, the resin burns off at approximately 600°F. (315°C.), leaving only an alloy-powder residue for brazing. Calculation of the amount of alloy used is of great importance in joining thin materials. Extruded ribbons of plastic-braze powder can also be applied to the surface of the work: typical amounts of braze-mixture ribbon required for given joints are quoted in the report.

Experiments to determine the extent to which capillarity flow may be utilized in brazing with the nickel-chromium-boron alloy showed that practical use may be made of this principle, permitting placing of the brazing material at a location at which destructive alloying is least harmful and the critical area of the joint is filled by capillarity only. Typical examples are demonstrated.

Alloys containing titanium and aluminium present some difficulty in brazing, and in materials such as Inconel and A.286 (both containing appreciable percentages of these elements) it has been found impossible to achieve structurally satisfactory joints. The difficulty can, however, be overcome by plating onto the parent material a thin coating of nickel or iron, which prevents formation, on its surface, of oxides of titanium and aluminium. The nickel may be deposited by electroplating or by the electroless process. Such coatings have no influence on the properties of the brazed joints, since the nickel or iron alloys with the brazing material.

Problems are also presented by composite assemblies, in that it is necessary to reconcile the opposing requirements of fast heating for good brazing and slow heating to minimize distortion due to variation in section of the members or to other variables. This difficulty can be overcome by using a two-cycle brazing technique. The retort containing the assembly is placed in a furnace at room temperature, and is heated at a rate of 100°F. (56°C.) per hour (i.e., at a rate sufficiently slow to prevent distortion), up to about 1750°F. (995°C.). On reaching that temperature (100°F. : 56°C. below the solidus of the brazing alloy) the entire retort is transferred to another furnace, which has been pre-heated to 2200°F. (1205°C.). The required fast heating through the melting range is thus achieved, and distortion is negligible, because of the relatively small temperature gradient established by rapid heating through the comparatively narrow elevated-temperature range. For small sections a two-part furnace can be used.

Nickel-containing Alloys for Brazing of Molybdenum

M. I. JACOBSON and D. C. MARTIN: 'Brazing Molybdenum for High-Temperature Service.'
Welding Jnl., 1955, vol. 34, Feb., pp. 65S–74S.

The specific object of the investigation reported was development of brazing techniques which would give, in molybdenum, joints showing sufficient strength and ductility to be useful in engineering applications. A particular interest was heat engines, where the use of molybdenum would permit employment of higher operating temperatures, with resultant increase in efficiency and power output.

A review of available literature indicated that the extreme brittleness of the joints, which is the outstanding difficulty, is due mainly to the presence of impurities, both in the base metal and in the weld area. A further cause of brittleness in welds made in commercial grades of molybdenum is recrystallization of the base metal.

Sixteen high-temperature materials were examined with regard to their suitability for use as brazing materials: all were selected as having a melting point of 1800°F. (982°C.) or above, and as being likely to show good strength at high temperatures. The compositions of the materials used are shown in the Table on the following page.

Molybdenum sheet from three sources was used: in two cases the material had been fabricated from sintered powder compacts, the third was made from arc-cast carbon-deoxidized ingots. Examination in the as-received condition showed that the bend-ductility of the sheet at room temperature was up to the standard required in commercial grades of sheet. Recrystallization studies were also made, as an aid to selection of brazing times.

The methods of joining used were:- vacuum brazing in an Inconel retort, oxy-acetylene torch brazing with a flux, induction brazing in vacuum, and induction brazing in argon. The criteria adopted were:- ability of the alloy to wet molybdenum, the relative advantages of various techniques *per se*, and the properties of the joints, at room temperature and at 1800°F. (982°C.). Much detailed experimental data and good illustrations are provided in the report.

The conclusions drawn are that, from the standpoint of quality of joint and practicability of technique, induction brazing in an argon atmosphere was the most satisfactory method. Room-temperature strengths of brazed joints were generally low, due to recrystallization of the molybdenum, and on account of notch effects inherent in the joints. Short-time tension tests at 1800°F. (982°C.) on joints induction-brazed in argon showed that the best results were obtained with Inconel, which produced a joint showing a shear strength of 18,800 p.s.i. (8·4 tons per sq. in.). The 100-hour shear strength, at 1800°F. (982°C.) of joints induction brazed with Inconel was 5,000 p.s.i. (2·23 tons per sq. in.). Of the cobalt-base alloys the best was Haynes No. 25, which produced a joint having a shear strength of 14,250 p.s.i. (6·35 tons per sq. in.). The 100-hour shear strength of the joints induction-brazed in argon with this alloy was 4,500 p.s.i. (2 tons per sq. in.).

Discussing the results, the authors point out that, although induction brazing in argon gave the best results, the tests demonstrated the possibility of satisfactory joining also by furnace-brazing in vacuum, oxy-acetylene brazing with a flux, and induction-brazing in vacuum. In practice, induction-brazing in argon would be limited by the size and shape of the parts being joined. It is also emphasized that before the data obtained can be put to practical use in high-temperature engineering, they must be supplemented by information on the creep characteristics of the brazed joints, and that all tests should be extended to temperature ranges higher than those used in this investigation. In view of the relative cheapness and ease of oxy-acetylene welding, further exploration of the practicability of this method appears desirable: the need is for a flux which will protect molybdenum up to about 2600°F. (1425°C.), and which can be easily removed after brazing.

Type of Alloy	Nominal Composition %	Liquidus	
		°F.	°C.
Super Nickel 826	Cu 70, Ni 30	2240	1227
Nickel	Ni 100	2650	1454
Inconel	Ni 80, Cr 14, Fe 6	2540	1393
Chromel	Ni 90, Cr 10	2550	1399
Wall Colmonoy No. 6	Ni 78, Cr 18, B 4	1950	1066
Monel	Ni 70, Cu 30	2370	1299
Hastelloy C	Ni 57, Mo 17, Cr 16, Fe 6, W 4	2380	1304
Haynes Stellite 21	Co 60, Cr 30, Si 5, Ni 3	2550	1399
Haynes Alloy 25	Co 55, Cr 20, W 15, Ni 10	2600	1427
18–8 Stainless Steel	Cr 18, Ni 8, bal. Fe	2600	1427
25–20 Stainless Steel	Cr 25, Ni 20, bal. Fe	2650	1454
Kanthal A–1	Fe 70, Cr 25, Al 5	2700	1482
Palladium–Copper	Pd 60, Cu 40	2200	1204
Palladium–Nickel	Pd 53, Ni 47	2200	1204
Palladium–Silver	Pd 60, Ag 40	2500	1371
Silver–Platinum	Ag 70, Pt 30	2200	1204

Austenitic Nickel-Chromium Steel Welding Electrodes: Influence of Production Technique

E. KAUHAUSEN and H. A. VOGELS: 'Successful Manufacture and Use of All-Austenitic Welding Electrodes.' *Metal Progress*, 1955, vol. 67, Jan., pp. 129–36.

The paper deals with a method developed for producing electrodes which will give fully austenitic welds, but be immune from susceptibility to weld cracking. The authors consider that the idea of preventing this defect by adjusting the electrode composition so that the weld metal contains a controlled proportion of ferrite is unsound for electrodes used in welding 16–13 chromium–nickel steel, as employed, for example, in superheater tubes and other fittings in power plant.

Metallographic examination of the behaviour of 16–13–Nb steel electrodes led to the conclusion that conditions at the grain boundaries of the steel are of paramount importance in this connexion, and tests with electrodes made from various heats of this type of steel confirmed the intimate relation between cleanliness of the metal and the ability to deposit crack-free welds showing good ductility and satisfactory fracture. The important differences of oxygen solubility in austenitic materials of varying composition is discussed, and it is pointed out that with falling temperature the oxygen solubility in the chromium-rich 16–13 steel decreases, and an essential part of the oxidized impurities in the melt will lie in the grain boundaries of the solidified weld metal. The increased sensitivity of such stably austenitic weld material is considered to be due to these grain-boundary conditions, which, when the weld metal is of a complex type, become increasingly complicated.

As a result of their investigations, the authors suggest the following requirements as being essential for the production of high-alloy austenitic welding electrodes which will give crack-free joints:

Sulphur content of the core wire should be controlled at 0·01 maximum. The primary grain size of the weld metal is also of importance; a coarse-grained material is more likely to produce a crack-sensitive weld. Deoxidation is a major consideration, and the carbon/silicon/manganese ratio is a vital factor. (This is discussed at some length, with data on results achieved with electrodes containing varying ratios of the three elements. Diagrams illustrate some of the proportions found (*a*) satisfactory, and (*b*) unacceptable).

Summarizing the information presented, it is concluded that, by closely controlled melting technique, appropriate balance of composition, and suitable deoxidation procedure, it is possible to produce core wire material giving crack-free and fully austenitic welds. Such material is being commercially produced in Germany. It is, however, admitted that so complex are the factors influencing the melting practice involved that the producer of electrode material is well advised to segregate the heats by individual tests. The authors find the tensile test suitable as a means of screening, paying particular attention to the value for elongation; they also carry out crack-sensitivity tests on coated electrodes made from core

wire from good heats. Basic lime coatings with suitable deoxidizing additions are used with the special electrode core wire: additions of rutile to such coatings, or the employment of rutile coatings, has been found to give poor results, even on core wire of satisfactory quality.

Welding of Stainless Steels: Correlated Summary of Information

H. THIELSCH: 'Stainless Steels: Welding Summary.' *Welding Jnl.*, 1955, vol. 34, Jan., pp. 22S–30S.

This summary (one of a series prepared under the auspices of the Welding Research Council) relates primarily to the selection of stainless-steel filler metals and their welding characteristics. It is based on correlated literature-review articles which have been published under the same authority over the period 1950–1954.

(Processes and procedures used in joining stainless steels have been the subject of an earlier review: *Welding Research Bulletin No.* 14, Sept. 1952; see *Nickel Bulletin*, 1953, vol. 26, Nos. 1–2, pp. 26–7).

The essential features of composition and structure characteristic of austenitic, martensitic and ferritic stainless steels are briefly reviewed, and the welding of the major commercial types in all three categories is discussed in the following classification:—

Welding of Austenitic Stainless Steels

Composition of main grades, wrought (A.I.S.I.) and cast (A.C.I.), with recommendations on electrodes of standard American types for welding them.

Carbide precipitation: cause, effects, means for prevention.

Preheat treatments, annealing, stress-relieving.

Welding the Martensitic Stainless Steels

Composition of A.I.S.I. and A.C.I. standard grades, with recommendations on welding electrodes and welding procedure.

Welding the Ferritic Stainless Steels

Composition of A.I.S.I. and A.C.I. standard grades, with recommendations on welding electrodes and welding procedure.

A table summarizes the welding characteristics of commercial stainless-steel electrodes and welding rods in current supply in the U.S.A. (trade designations, nominal compositions, type of current used, type of electrode covering, standard electrode colour marking used by National Electric Manufacturers' Association, applications of the respective types).

Overlaying of Steel and Cast Iron with High-Nickel Alloys

G. R. PEASE, H. B. BOTT and H. C. WAUGH: 'High-Nickel Overlays on Ferrous Metals.' *Welding Jnl.*, 1955, vol. 34, Jan., pp. 40–8.

In overlaying of ferrous bases with corrosion-resisting and other non-ferrous materials certain problems arise which are not necessarily encountered in welding the bulk overlay material to itself. Dilution of the overlay with iron introduced from the base may seriously vitiate the behaviour of the surfacing material, both with regard to corrosion-resistance and ductility.

This paper reports experiments made to ascertain the inherent character of the problems arising in this connexion, and to devise methods for overcoming them. The overlay metals studied comprised Monel, K Monel, Inconel, and 80-20 nickel-chromium alloy, deposited, in most cases, as a one- or two-layer overlays on a mild-steel base. A few exploratory tests were also made with grey cast iron as the base material, but it is considered that the usefulness of any of the high-nickel filler metals for deposition on cast iron is extremely limited. The overlays were deposited by three methods: (1) coated electrode welding, (2) inert-gas consumable-electrode welding, and (3) the inert-gas tungsten-arc process. A table shows the compositions of all-weld metal deposited from the various rods used.

The results of the individual series of tests are recorded in detail, and the characteristics of satisfactory and unsatisfactory overlays are discussed and illustrated.

The results show that (in addition to the introduction of an intermediate 'barrier' layer of a compatible metal) it is possible in many cases to reduce the amount of base-metal pick-up by observing the following precautions:-(1) operation of the electrode at the minimum current consistent with proper burn-off, (2) development of optimum bead contour and thickness, and (3) dissipation of as much as possible of the 'digging' energy of the arc stream in the molten pool and as little as possible in the base metal. Bead contours considered (*a*) good, or (*b*) poor, are illustrated in this paper, and detailed recommendations are made on overlaying procedure, to ensure, for each of the materials, that dilution with base metal is minimized, and sound and ductile overlays are achieved. It is also urged that, as a general precaution, cleanliness of the basis-metal surface is a vital factor in securing satisfactory adhesion and properties.

Influence of Cold Work and Tempering on Structural Changes in Austenitic Steel

B. CINA: 'The Metastability of Austenite in an 18–8 Cr-Ni Alloy.' *Jnl. Iron and Steel Inst.*, 1955, vol. 179, Mar., pp. 230–39.

It has for some time been well known that if an initially austenitic 18–8 chromium-nickel steel is quenched after exposure within the temperature range 450°–800°C., or is simply cold-worked without any such thermal treatment, a body-centred-cubic phase is formed. Whilst the martensitic mode of formation of the b.c.c. phase observed after cold work is now well established, there has been considerable difference of opinion with regard to the mechanism of formation of the phase observed after tempering. Some investigators favour the view that it is formed

at the tempering temperature; others consider that it forms on cooling. Relevant literature is considered.

The work described in the present paper was planned to obtain a quantitative measure of the extent of the breakdown which can be obtained in a typical commercial 18-8 chromium-nickel steel by cold work and/or tempering. Metallographic, thermomagnetic, and room- and high-temperature X-ray diffraction methods were used.

The extent of the γ-α transformation was measured in specimens deformed at temperatures ranging from room temperature to -196°C., and in softened and cold-worked samples tempered within the range 500° to 800°C.

The results, very extensive details of which are given, indicate that the extent of austenite breakdown after tempering is primarily related to the loss of carbon by its precipitation as $(Cr, Fe)_{23}C_6$, and that this γ-α transformation occurs only on cooling from the tempering temperature, and below about 300°C. It is also shown that isothermal formation of ferrite at room temperature occurs after sensitizing treatments.

An *Appendix*, 'High-Temperature X-Ray Diffraction Examination of an 18-8 Cr-Ni Alloy', by B. CINA and J. D. LAVENDER (*ibid.*, p. 240) reports confirmatory observations made on a cast low-carbon 18-8 steel.

Preserving the Corrosion-Resistance of Nickel-Chromium Stainless Steels

H. BROWN: 'Proper Treatments Preserve Properties of Types 321 and 347 Stainless.' *Iron Age*, 1954, vol. 174, Nov. 25, pp. 93-5.

This article gives a relatively elementary account of the characteristics of the stabilized grades of 18-8 chromium-nickel steel, and emphasizes the possibility of corrosion of such steels if they are incorrectly handled, if the surface becomes contaminated with materials which will give rise to corrosive attack, or if they are welded by unsuitable procedure. Typical examples of failure are quoted to demonstrate the importance of correct handling: these include corrosion due to penetration of metallic zinc (e.g., from dies, marking pencils, etc.), cracking due to excessive carbon pick-up in welding, stress-corrosion in stainless steel welded to carbon steel and operating under fluctuating temperature conditions, and cracking due to incorrect grinding.

Anodic Protection of Stainless Steel in Nitric Acid, by Coupling with Aluminium

J. F. WILLGING, J. P. HIRTH, F. H. BECK and M. G. FONTANA: 'Corrosion and Erosion-Corrosion of Some Metals and Alloys by Strong Nitric Acid.' *Corrosion*, 1955, vol. 11, Feb., pp. 31-9.

The experiments reported in this paper show that aluminium acts as a sacrificial anode when coupled with nickel-chromium stainless steel in fuming nitric acid. Such a couple is effective in providing protection to the steel over the whole of the temperature range investigated—ambient to 160°F. (70°C.). Erosion-corrosion data indicate that increasing velocity of acid flow causes decrease in the rate of attack on stainless steel but accelerates the attack on the aluminium. These effects are explained on the basis of (*a*) removal of reaction and decomposition products of the acid from the surface of the stainless steel, and (*b*) erosion of nitrate film, and possibly oxides, from the aluminium surface. Contamination of the acid with aluminium nitrate resulting from the severe corrosion on the coupled aluminium, especially at raised temperature, presents a serious problem in relation to practical utilization of this means of providing protection for stainless steel. Methods for overcoming these undesirable effects are under investigation. (Control tests on uncoupled specimens of the stainless steel and the aluminium are also reported, and a full description is given of the experimental conditions and the erosion-corrosion test equipment used.)

Polarization studies on both materials were carried out to provide additional information on the corrosion behaviour of the aluminium-stainless steel couple.

Polarization of Nickel and Nickel-Copper Alloys in Sodium-Chloride Solutions

See abstract on p. 59.

Corrosion by Alternate Exposure to Liquid and Gaseous Fluorine

R. M. GUNDZIK and C. E. FEILER: 'Corrosion of Metals by Alternate Exposure to Liquid and Gaseous Fluorine.' *Nat Advisory Committee for Aeronautics, Tech. Note* 3333, Dec., 1954; 10 pp.

Records in the literature show that nickel, Monel and aluminium are resistant to attack by gaseous fluorine at temperatures up to 450°C., whereas the resistance of stainless steels is unsatisfactory above 200°-250°C. No information was, however, previously available with regard to corrosion of metals by liquid fluorine at the temperature of liquid nitrogen, or under alternate exposure to liquid and gaseous fluorine.

The experiments reported in this Note were made to determine the corrosion of metallic materials exposed in conditions occurring when fluorine is repeatedly condensed. Data were obtained by alternately exposing the inner surfaces of small tubes to gaseous and liquid fluorine, for a total test period of $3\frac{1}{2}$ months. The apparatus used is illustrated.

The specimens exposed were two types of aluminium-base alloy, niobium-stabilized and titanium-stabilized austenitic nickel-chromium steels, commercial nickel, and a brass of low lead content. Behaviour in the test conditions was evaluated by visual examination, measurement of weight changes, and photomicrographic examination.

Corrosion was negligible in all conditions of test, and no visual differences were observed between surfaces exposed to the gaseous phase only and those exposed to both liquid and gaseous fluorine.

Materials for Handling Hydrofluoric Acid

'Hydrofluoric Acid Handling.'
Industrial Chemist, 1954, vol. 30, Dec., pp. 609–10.

This article outlines the uses and limitations of various materials of construction commonly employed in service involving contact with aqueous and with anhydrous hydrofluoric acid. The following notes are extracted from the section concerned with metallic materials:—

'*Aqueous Hydrofluoric Acid*

The reactivity of aqueous hydrogen fluoride increases with increasing dilution and the concentrated acid is therefore much easier to handle than dilute acid. Concentrations above 60 per cent. can be handled safely in steel equipment previously passivated with slightly more dilute acid, but if water is allowed to enter the equipment the inner surfaces should be treated to restore the passive lining. Carbon steel is widely used for hydrofluoric acid in concentrations above 80 per cent. up to 150°F. (65°C.). Stainless steel is not a suitable material, due to the removal of its protective film by hydrofluoric acid . . . Cast iron is not recommended, owing to the tendency to graphitic corrosion . . . High-silicon iron alloys are not suitable for use in any type of hydrofluoric acid service. Lead has been used with unaerated 60 per cent. acid up to the boiling point (184°F.: 84°C.) but it should be used cautiously above room temperature. Aluminium is not suitable.

'*Nickel and Copper Alloys*

Monel is resistant to all concentrations of the acid, and is satisfactory up to 250°F. (120°C.) except in highly aerated solutions. Nickel should not be used above 170°F. (76°C.) in dilute acid solution, and in commercial 60–65 per cent. acid it is corroded severely at room temperature. Monel is generally more resistant than nickel or copper, and finds wide application for HF service. In aerated solutions nickel-molybdenum-base alloys of the Chlorimet types can be used to advantage. Copper- and molybdenum-containing stainless steels of Durimet 20 type can be used for hydrofluoric acid service, especially under oxidizing conditions, in concentrations below 10 and above 60, per cent. at room temperature: they have also been used for 80 per cent. acid at 35°C. Valves of this type of material are used by refineries in the HF alkylation process, and pumps, jets, and other parts are also made from it. The main use of this material is for aerated solutions. Worthite (austenitic nickel-chromium steel containing molybdenum) is also useful for aerated acids above 60 per cent. concentration. For acids below 40 per cent. concentration nickel-molybdenum-iron alloys of the Hastelloy A type can be used at temperatures below 55°C. Centrifugal pumps for aqueous acids are made of Monel, nickel bronze, or steel.

'*Anhydrous Hydrofluoric Acid*

The most common material for service with the anhydrous acid is mild steel, which is satisfactory up to 150°F. (65°C.). Stainless steel can be used at room temperature. Copper is also quite satisfactory, but is attacked in the presence of sulphur dioxide and oxygen. Copper alloys, in common with some stainless steels, are sensitive to velocity effects. Lead is not recommended.

'Above temperatures of 200°F. (93°C.) neither steel nor copper is satisfactory, the nickel alloys being more resistant to the anhydrous acid at elevated temperatures. Monel finds wide application for anhydrous acid service in valves, bubble caps, pumps, etc.'

Chemical and Electrochemical Polishing of Metals and Alloys: Patent Literature

See abstract on p. 58.

The Salt-Spray Test: Acetic-Acid Modification

See abstract on p. 61.

Spectrochemical Analysis of High-Nickel Alloys

W. O. GERBER and W. H. TOBIN: 'A Spectrochemical Method for the Analysis of M-252 Nickel-base High-Temperature Alloy and the Preparation of Standards by Powder Metallurgy.'
Applied Spectroscopy, 1954, vol. 8, pp. 120–5.

Analysis of M-252 alloy*, for which wet methods involving long times have previously been necessary, can now be made in two hours by the procedure described in this paper. Molybdenum, cobalt, iron and chromium are determined by X-ray fluorescence: titanium, aluminium, manganese and silicon are estimated by ultra-violet emission spectroscopy, and carbon by the high-frequency induction furnace. Nickel is determined by difference. Preparation of standard samples, using powder-metallurgy technique, is also described.

PATENTS

Extraction of Nickel and Cobalt

An aqueous acid solution containing cobalt, nickel, and usually ammonium salts of the acid, is adjusted (by sulphuric acid) to the correct degree of acidity and dilution. The solution is then treated with a reducing gas, at elevated temperatures and under regulated acidity conditions. A succession of such treatments, under varying and closely controlled conditions, precipitates a successive series of products which are separately collected. The first product comprises high-purity nickel powder, the last product is a substantially nickel-free cobalt powder.

F. A. SCHAUFELBERGER, assignor to CHEMICAL CONSTRUCTION CORPN. *U.S. Pat.* 2,694,005.

* The composition quoted for the alloy examined is iron 3.5, chromium 19, cobalt 10, molybdenum 10, titanium 2.5, aluminium 0.75, carbon 0.10, manganese 1.00, silicon 0.65, nickel 52.5, per cent.

Nickel Powder in Magnetic Couplings

The magnetic material of a coupling consists of finely divided nickel particles, alone or mixed with iron particles and/or nickel-coated iron particles. Nickel may be deposited on the iron particles by the electroless plating process.

VICKERS, INC. (inventors, F. G. LOGAN and D. W. RAU). *Brit. Pat.* 722,027.

See also a related patent which specifies that the magnetic material of the coupling consists of iron particles coated with a less readily oxidizable magnetic metal such as nickel, used either alone or with uncoated iron particles, and without any liquid or solid lubricant additive.

VICKERS, INC. (inventor, D. W. RAU). *Brit. Pat.* 722,089.

Oxidation of Nickel for Use in Electric Batteries

Formation of a coating of nickel oxide is beneficial in conferring resistance to certain types of corrosion, and in some applications, such as alkaline primary electric cells in which porous nickel electrodes are used, additional corrosion-resistance would be valuable. Coating of the electrode with a layer of green nickel oxide is not, however, practicable, because such an oxide layer is characterized by high electrical resistance. According to the patent, this difficulty is overcome by introducing lithium atoms into the crystal lattice of the nickel oxide, creating a black oxide coating, the conductivity of which is increased, by comparison with that of the green untreated nickel oxide, by a factor as great as 10^6. The method of introducing the lithium, the production of the electrode from nickel powder, and the type of cell are also covered.

F. T. BACON and BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCN. *Brit. Pat.* 725,661.

Electrodeposition of Bright Nickel

Bright coatings are electrodeposited from an aqueous solution of nickel sulphate and/or nickel chloride which contains coumarin sulphonic acid (0·5–3·0 g./L.), acting as the brightening agent. Benzene sulphonamides or sulphonimides are also preferably present.

H. BROWN, assignor to UDYLITE CORPN. *U.S. Pat.* 2,694,041.

Smooth and Buffable Nickel Electrodeposits

To improve the smoothness and buffability of deposits there is added to a nickel plating bath of the nickel sulphate, chloride, fluoborate, or sulphamate type an addition agent of the class consisting of coumarin and its substitution products of specified types. Formaldehyde is also present. Typical baths are described.

A. H. DU ROSE and K. S. WILLSON, assignors to HARSHAW CHEMICAL CO. *U.S. Pat.* 2,683,115.

Electroless Deposition of Nickel and Other Metals

Nickel plating by immersion is carried out in a bath consisting of an aqueous solution of a nickel salt, a hypophosphite, a salt of a simple short-chain saturated aliphatic dicarboxylic acid (e.g., sodium succinate), and a fluoride. The pH is 4·5–6·5. Copper, silver, gold, iron, cobalt, nickel, palladium or platinum bases can be thus coated with nickel.

G. GUTZEIT, assignor to GENERAL AMERICAN TRANSPORTATION CORPN. *U.S. Pat.* 2,694,019.

Immersion Plating of Aluminium and Aluminium Alloys

Aluminium and its alloys are nickel-plated by immersion in a bath comprising an aqueous solution of a nickel salt (e.g., nickel chloride), a hypophosphite (e.g., sodium hypophosphite), a nitrate, and preferably a fluoride. The absolute concentration of nitrate anions is 0·15–0·50 mole/L. The initial pH is preferably 4·0–5·5.

R. R. RESCHAN and A. KRIEG, assignors to GENERAL AMERICAN TRANSPORTATION CORPN. *U.S. Pat.* 2,694,017.

Electrolytic Polishing of Nickel-containing Steels and Alloys

In electrolytic polishing of stainless steel, iron, nickel, chromium and their alloys, in an electrolyte based on a mixture of sulphuric and orthophosphoric acids, sulphuric acid is continuously introduced into the bath, in amount sufficient to make up for losses and to react with the soluble salts of compounds of the phosphoric acid, thus causing precipitation of insoluble salts, compounds or complexes of sulphuric acid.

ELECTROPOL, LTD. (inventor, P. A. CHARLESWORTH). *Brit. Pat.* 706,473.

Coating of Aluminium viâ Nickel Carbonyl

A multi-layer metal product resistant to blistering and separation of the layers on heating is made in the following manner:- a thin layer of nickel is deposited on an aluminium base by exposing it to an atmosphere of gaseous nickel carbonyl; the layer so deposited is 0·00001–0·00025 in. thick.

The material is then heated to remove the gas in the nickel layer, and a second layer of nickel, thicker and denser than the first, is deposited by renewed exposure to the carbonyl, in conditions producing decomposition.

A. O. FINK, assignor to COMMONWEALTH ENGINEERING CO. *U.S. Pat.* 2,682,702.

Nickel-containing Heavy Alloy

A heavy alloy contains tungsten and/or molybdenum 62·5–90, chromium 1–22·5, nickel 5–10, copper 0–5, per cent.

GENERAL ELECTRIC CO., LTD. *Australian Pat.* 160,077.

Nickel-Iron-base Alloys having Low Temperature Coefficient of Elasticity

Alloys containing balanced amounts of nickel (28–39 per cent.) and iron (64–44 per cent.), plus controlled percentages of molybdenum *or* chromium *or* tungsten, have low temperature coefficients of elasticity. The preferred composition is given as nickel 30, molybdenum 10, manganese up to 2, per cent., iron balance. Up to 10 per cent. of other elements which do not affect the elastic properties may be added: these include manganese up to 2, carbon up to 0·25, aluminium up to 6, silicon up to 5, per cent.

M. E. FINE, assignor to WESTERN ELECTRIC CO., INC. *French Pat.* 1,070,903.

Nickel Alloys in Glass-to-Metal Seals

A glass-to-metal seal consists of an iron-alloy member on which is electrodeposited first a layer of silver and second a thin layer of zinc or cadmium. A glass member is fused to the layer of the second coating metal. The iron alloy is preferably of the composition iron 57–59, nickel 43–41 per cent.

GENERAL ELECTRIC COMPANY (U.S.A.). *Brit. Pat.* 721,015.

Anisotropic Nickel-Alloy Magnets

A magnetically anisotropic permanent magnet is made from an alloy containing nickel 12·5–14·5, aluminium 7·5–8·5, cobalt 23·5–25·5, copper 2·9–3·3, carbon less than 0·05, niobium 0·5–3·25, per cent., iron balance. Preferred composition is quoted.

D. HADFIELD, assignor to W. JESSOP AND SONS, LTD. *U.S. Pat.* 2,694,166.

See also a related patent which specifies similar nickel, aluminium, cobalt, copper and carbon contents, with niobium about 1·5, tantalum about 1·5, per cent., iron balance.

D. HADFIELD, assignor to W. JESSOP AND SONS, LTD. *U.S. Pat.* 2,694,167.

Vanadium Additions to Nickel-Chromium Case-Hardening Steels

It is claimed that a trace of vanadium added to nickel-chromium case-hardening steels (preferably containing more than 1·7 per cent. of nickel and not more than 0·3 per cent. of carbon) accelerates the transformation to the pearlitic condition, thus avoiding occurrence of cracks on chilling after carburizing. Traces of molybdenum, manganese, tungsten, boron, copper and aluminium may also be present.

BOCHUMER VEREIN, A.G. *Belgian Pat.* 531,268.

Nickel-containing Rivet Steel

Steel for rivets contains carbon up to 0·12, manganese 0·2–0·6, nickel 0·7–1·7, copper 0·6–1·2, silicon 0·6–1·2, aluminium 0·1–0·5, per cent., iron balance. A typical steel has the composition carbon 0·06, manganese 0·47, nickel 1·3, copper 0·7, silicon 0·93, aluminium 0·10, per cent., iron balance.

S. EPSTEIN and K. F. HAUPT, assignors to BETHLEHEM STEEL CO. *U.S. Pat.* 2,694,627.

Steel for Use at Sub-Zero Temperatures

Articles required to resist impact at sub-zero temperatures are made from a wrought steel containing carbon 0·01–0·2, manganese 0·2–1, silicon 0·02–0·8, copper 0·25–1·25, nickel 0·5–3, chromium 0·5–1·5, aluminium 0·08–0·3, nitrogen 0·013–0·03, per cent., balance iron and incidental impurities. The steel has an impact-transition temperature not above −170°C.

C. M. OFFENHAUER, assignor to UNION CARBIDE AND CARBON CORPN. *U.S. Pat.* 2,679,454.

Clad Material for Use in High-Temperature Parts

A material suitable for flame tubes, aircraft exhaust manifolds and other parts working at high temperatures and subject to thermal shock comprises a composite sheet metal consisting of (1) a foundation layer predominantly of nickel and chromium and forming at least 50 per cent. of the total thickness of the composite, (2) a layer of copper or an alloy rich in copper, constituting 25–30 per cent. of the total and serving as a heat-dispersing medium, and (3) an outer layer of nickel and/or cobalt (with or without a final flash of chromium or rhodium), forming 10 per cent. of the total thickness. This outer layer, which protects the copper or copper-alloy layer from oxidation, may be electrodeposited, as may the copper-base layer. The foundation and the copper or copper-alloy layer may be bonded by heating.

HENRY WIGGIN AND CO., LTD. (inventor, J. O. HITCHCOCK). *Brit. Pat.* 722,121.

Electrical-Resistance Alloys

Resistor elements immune from selective oxidation of chromium contain chromium 18–22, niobium 1–2, silicon 1–2, iron 0·2–2, manganese trace–2·0, carbon 0·02–0·15, per cent., impurities not more than 1 per cent., balance nickel.

BRITISH DRIVER-HARRIS CO., LTD. *Brit. Pat.* 722,405.

Improved electrical-resistance alloys contain chromium 10–25, calcium 0·005–0·05, cerium 0·025–0·06, silicon 1·15–2·0, per cent., nickel balance. Iron up to 2, aluminium up to 1, carbon up to 0·3, copper up to 0·16, manganese up to 3 and cobalt up to 15, per cent., may also be present. Preferred compositions are cited.

MOND NICKEL CO., LTD. (inventors, W. BETTERIDGE and H. LEWIS). *Brit. Pat.* 722,145.

Nickel-Chromium/Nickel-Silicon Alloy Thermocouple

The electropositive element of a thermocouple is a nickel alloy containing 10–25 per cent. of chromium, and the electronegative element is a nickel alloy containing 2–7 per cent. of silicon. Additions of up to 2 per cent. of niobium may be present in the nickel-chromium alloy.

S. POCH and J. C. LEWIS, assignors to DRIVER-HARRIS CO. *Canad. Pat.* 508,131.

Precipitation-Hardenable Stainless Steel

A nickel-chromium-copper-aluminium steel in which the copper and aluminium are fully soluble on annealing and quenching, and can be precipitated by a single heat-treatment, contains nickel 3·0–7·0, chromium 14·0–19·0 (related to the nickel according to a diagram shown in the patent), carbon up to to 0·15, aluminium 0·8–1·75, copper 2–5, manganese and silicon up to 2 per cent., iron balance. A preferred composition is given.

H. TANCZYN, assignor to ARMCO STEEL CORPN. *U.S. Pat.* 2,694,626.

Precipitation-Hardening Treatment of Austenitic Steels

Precipitation-hardenable steels free from phosphorus other than as a residual impurity, and falling within the compositions covered by British Patents 669,131; 616,207, and 669,579 (and other compositions) are reduced in area by 5–40 per cent. at a temperature below 800°C., after normal solution treatment and before precipitation treatment. Alternatively, the intermediate mechanical treatment may be omitted.

H. W. KIRKBY, C. SYKES and C. STOKES. *Brit. Pat.* 722,809.

Free-Machining Corrosion-Resisting Steels

The corrosion-resistance of free-machining steels containing chromium 18–29, nickel 4–8, sulphur 0·1–0·75, carbon less than 0·08, molybdenum less than 0·05, per cent., iron balance, is improved by maintaining manganese or zirconium at less than 0·1 per cent.

A. P. V. CO., LTD. (inventors, G. H. BOTHAM, J. F. LANCASTER and D. W. O. DAWSON). *Brit. Pat.* 722,814.

Corrosion-Resisting Steel for Springs

Corrosion-resistant spring material characterized by high elastic modulus and high tensile strength contains nickel 6–10, chromium 12–20, silicon 0·8–2, and/or molybdenum 0·4–3, per cent., balance iron. Titanium 0·4–3 per cent., and carbon not more than 0·3 per cent. may also be present. A preferred composition is given. The steel is quenched from 900°–1200°C.

SANDVIKENS JERNVERKS A.B. *Brit. Pat.* 722,427.

Low-Carbon Stainless Steel for Surgical Use

A metal container for liquids which are to be injected into a living human or animal body, for therapeutic, anaesthetic or like purposes, is made from a stainless steel containing chromium 18–20, nickel 11–15, molybdenum 3–4, per cent. Carbon is preferably not more than 0·04, manganese 1–2, phosphorus not more than 0·03, sulphur not more than 0·03, and silicon 0·3–0·6, per cent.

R. P. SCHERER CORPN. *Brit. Pat.* 721,164 (Addition to *Brit. Pat.* 672,798).

Brazing Alloy

A brazing alloy for use in joining ferrous and non-ferrous materials contains copper 15–50, nickel 10·2–18, per cent., de-oxidizer agent(s), preferably silicon or phosphorus, 0·1–1 per cent., zinc balance. Tin 0·1–1, cadmium 0·1–15, and manganese 0·1–15, per cent. may also be present.

STÉ. DES SOUDURES CASTOLIN, S.A. (inventor, R. D. WASSERMAN). *French Pat.* 1,076,884.

Coated Austenitic Steel Welding Electrode

The core of an electrode for welding steel contains chromium 17–20, nickel 8–10, manganese 1–3, silicon up to 3, carbon 0·05–0·3, per cent., iron balance. The core is coated with a mixture containing calcium fluoride, calcium carbonate, titanium dioxide, calcium silicate, and ferro-silicon in specified amounts, together with metallic chromium powder (35–45 per cent.). The preferred composition of the core is chromium 19, nickel 9, manganese 2, carbon 0·15, per cent., iron balance.

STÉ. DES SOUDURES CASTOLIN, S.A. *French Pat.* 1,073,182.

(*Cf. Brit. Pat.* 720,834, accepted in the name of EUTECTIC WELDING ALLOYS CO., LTD. (inventor, R. D. WASSERMAN).

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

THE MOND NICKEL COMPANY LIMITED
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